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Technical Note

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INVESTIGATION OF SPRAY-APPLIED POLYURETHANE FOAM ROOFING SYSTEMS-II

ABSTRACT An experimental investigation of the performance and properties of spray-applied polyurethane foam roofing systems is described. Polyurethane foam studied included densities of 2.0, 2.5, and 3.0 pcf. Elastomeric coating systems included catalyzed silicones, moisture-curing silicones, a water-based silicone, butyl-hypalons, hypalons, acrylics, neoprene-hypalon, butyls, chlorinated rubber, fibrated aluminum-asphalt, catalyzed urethanes, moisture-curing urethanes, urethane-hypalons, neoprene asphalt-acrylic emulsion, rapid-cure urethanes. A rigid cementitious coating system was also included. Properties of the coating system such as adhesion, tensile strength, wind-driven-rain absorption, impact strength, and elongation are also reported. After exposure periods up to almost 12 years, eleven of the 54 coating systems were rated excellent or very good at all three of the exposure sites - seashore, desert, and mountain. They included catalyzed silicone with granules, moisture-curing silicone with granules, two acrylic emulsions, three acrylic emulsions with granules, two catalyzed urethanes, one moisture-curing urethane with granules, and a urethane-silicone. Effects of foam density and relative importance of physical properties on coating system performance are also reported. Degradation of uncoated foam is also reported. Glass transition temperature tests by the impact and DSC methods performed by USBR on contract are also reported.

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METRIC CONVERSION FACTORS

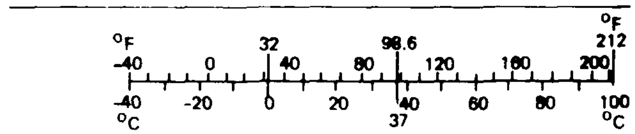
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10 286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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13. ABSTRACT *(Maximum 200 words)*

An experimental investigation of the performance and properties of spray-applied polyurethane foam roofing systems is described. Polyurethane foam studied included densities of 2.0, 2.5, and 3.0 pcf. Elastomeric coating systems included catalyzed silicones, moisture-curing silicones, a water-based silicone, butyl-hypalons, hypalons, acrylics, neoprene-hypalon, butyls, chlorinated rubber, fibrated aluminum-asphalt, catalyzed urethanes, moisture-curing urethanes, urethane-hypalons, neoprene asphalt-acrylic emulsion, rapid-cure urethanes. A rigid cementitious coating system was also included. Properties of the coating system such as adhesion, tensile strength, wind-driven-rain absorption, impact strength, and elongation are also reported. After exposure periods up to almost 12 years, eleven of the 54 coating systems were rated excellent or very good at all three of the exposure sites - seashore, desert, and mountain. They included catalyzed silicone with granules, moisture-curing silicone with granules, two acrylic emulsions, three acrylic emulsions with granules, two catalyzed urethanes, one moisture-curing urethane with granules, and a urethane-silicone. Effects of foam density and relative importance of physical properties on coating system performance are also reported. Degradation of uncoated foam is also reported. Glass transition temperature tests by the impact and DSC methods performed by USBR on contract are also reported.

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BACKGROUND

Over the past several years, maintenance of roofs and roofing systems has become an ever-increasing problem. The problem has been compounded by changes in composition of bitumen and felts, by materials shortages, by poor workmanship, and by other factors which lead to poor performance and short service life of these waterproofing systems. Information available at the Naval Civil Engineering Laboratory (NCEL) suggests that current annual maintenance costs for roofs at Naval shore activities is at least 50 million dollars and may be as much as 100 million dollars.

Because of the increasing seriousness of the roof maintenance problem, NCEL was requested by the Naval Facilities Engineering Command (NAVFAC) to investigate roofing systems. This research was to be directed toward all areas of roofing problems. The objective of the investigation was to provide a significant reduction in maintenance costs for roofing systems at Naval shore bases by defining existing problems and identifying conventional and new materials and methods that might eliminate or alleviate these problems. An extensive survey of Naval shore bases was conducted in different climatic areas to define and delineate their most recent roofing problems (Ref 1).

The experimental program was to cover a broad spectrum of roofing problem areas that were either known or would be delineated by the roofing survey. In pursuing this aspect of the program, funds were provided to the National Institute of Standards and Technology (NIST - formerly the National Bureau of Standards) to conduct a state-of-the-art study covering the effect of moisture on built-up roofs (BUR) (Ref 2). In addition to this contractual effort covering the effect of moisture on BURs, support was also provided to the U.S. Bureau of Reclamation (USBR) Research Laboratories to aid in their preparation of a report on an extensive research effort which USBR had conducted earlier in new roofing systems (Ref 3).

Early in the NCEL roofing research program, NAVFAC requested that the Laboratory cooperate with the Northern Division of NAVFAC (NORTHNAVFACENGCOM) to develop and carry out an experimental field investigation of spray-applied polyurethane foam (PUF) roofing systems at the Naval Reserve Center (NRC), Clifton, New Jersey. Results of this investigation are presented in References 4 and 5. Because of the requirement to assist in the development of plans for the experimental field investigations of PUF roofing systems, the original experimental roofing investigations at NCEL were directed toward PUF materials and coatings for protecting PUF from weathering. Results of initial small scale field tests were reported in Reference 6. These investigations took on added significance because of the requirement in the DOD Construction Criteria Manual (1972) that all new roofs have a "U" value of 0.05 Btu/(hr)(ft^2)($^\circ$F) (Ref 7).

NCEL conducted a major investigation into sprayed polyurethane roofing systems. In addition to those efforts mentioned above, the investigation also included: "Decay of Thermal Conductivity of Aged PUF" (Ref 8),

"Fire Tests of PUF Applied Directly to Metal Decks" (Ref 9), "Development of Guidelines for Maintaining PUF Roofs" (Ref 10), and "Performance of PUF Roofs Exposed in Tropical Environments" (Ref 11). Reports covering basic information on the requirements for planning and installing good foam roofs were also prepared (Refs 12, 13).

INTRODUCTION

Over the past 15 years, spray-applied PUF has been utilized in roofing systems in ever-increasing quantities. The fact that this usage continues to increase significantly is indicative of its acceptance in many areas. However, as with any new material, this utilization has not been without problems. PUF roofing systems are not cure-alls for each and every roofing problem. Unfortunately, during the initial years of their use, PUF roofing systems were often proclaimed, by contractors and material suppliers alike, to be a panacea for all roofing problems. As with any new material, those in the industry needed time to gain knowledge and experience. For example, PUF materials degrade rapidly when exposed to sunlight and must be protected. During the early years, many different coating systems were used to achieve this protection and, as might be expected, the main criterion often was "the cheaper, the better." Little time was required, however, to learn that just any coating system would not provide the proper protection. It was found that many coating systems that performed well when applied to other substrates would crack and flake from a foam surface within 6 to 18 months, thus exposing unprotected foam to sunlight. It soon became obvious that only an elastomeric type of coating system has the flexibility, elongation, and tensile strength required to accommodate the rather large expansion and contraction inherent in spray-applied PUF when subjected to ambient thermal cycling.

Because of their lower compressive and tensile strengths, PUF materials are more susceptible to physical abuse than many conventional roofing materials. As a result, roofing contractors, maintenance personnel, and others who walk or work on PUF roofing systems must learn to treat such roofs with the proper respect in order to prevent or minimize mechanical damage.

As with other roofing systems, PUF materials must be applied to properly prepared substrates or roof decks. Application over a water-soaked BUR system or over a surface that is dirty or covered with a weathered, chalky paint system would be doomed to failure. This would be true regardless of whether the roofing maintenance system being applied was PUF or any other roof maintenance system.

Finally, spray-applied PUF has a somewhat uneven surface at best and, if improperly applied, can have a very rough surface texture called "popcorn" or "treebark." Not only is the texture of such foam quite rough, but the physical characteristics of the foam itself are frequently inferior. The quality of surface texture that can be obtained is largely a function of the skill of the foam spray operator, including his ability to properly adjust the spray equipment. Popcorn or treebark surfaces on a PUF roof are completely unacceptable because they are very difficult to

coat properly. Since coatings tend to flow from high areas into low areas, the high points do not have sufficient minimum thickness, leading to rapid deterioration of the PUF roofing system.

In the early days of PUF roofing systems, shaving of the foam surface was accomplished with a special machine. This provided a smoother surface for the coating but the shaving action exposed the cell structure of the foam. In addition, the protective coating system was required to bridge the open cell structure, which greatly reduced the bonding surface for the coating. The exposed cell structure also tended to promote pinholing in a coating placed over it, providing focal points for failure of the coating system. For these reasons, such a procedure is not recommended.

A direct result of potential problems with PUF roofing systems was that many reliable roofing contractors were in and out of the spray-applied PUF roofing business rapidly. Since there seemed to be no solution for some of these problems, NCEL decided to concentrate its early research on spray-applied PUF roof systems. The research was intended to generate data that provides guidelines for coating systems to protect PUF materials used in a roof system.

EXPERIMENTAL

The principal objectives of this investigation were to determine how long the candidate PUF roofing systems perform satisfactorily when exposed to the weather and which of the candidate systems were superior. The PUF systems were exposed to three different climatic conditions, i.e., seashore, desert, and mountain. Experience has shown that if the PUF is properly applied to a suitably prepared substrate, the performance of the system is primarily dependent on the performance of the protective elastomeric coating system. That is, with a high quality foam, if the coating performs well, the PUF roofing systems as a whole can generally be expected to perform well. The performance of the coated PUF panels at the three sites was monitored periodically.

Selection of Materials

Spray-Applied PUF Materials. At the time this investigation was being initiated, the National Institute of Standards and Technology (NIST - formerly the National Bureau of Standards) completed a report, "Guidelines for Selection of and Use of Foam Polyurethane Roofing Systems" (Ref 14). In preparing plans and selecting materials for the field investigation at NRC, Clifton, New Jersey, NCEL conducted a state-of-the-art survey of materials and methods for application of PUF roofing systems. Information obtained in this survey together with the criteria set forth in Reference 14 were used in selecting the spray-applied PUF materials.

Foam Systems Used. Early in this work, foam having a density of 2 lb/ft^3 was considered the standard of the industry. Many of these foams were good but some did not have the proper Underwriters Laboratories (UL) fire credentials. A short time later, 2.5 lb/ft^3 density foam became readily available and as the program continued, 3 lb/ft^3

density foam became the standard of the industry. In fact, the more important property of the foam is compressive strength rather than density and we have for some time recommended a minimum compressive strength of 40 psi. Generally, a 2.5 to 3 lb/ft^3 density foam is required to meet the 40 psi compressive strength requirement.

A wide variety of spray foams were included in the program, both from the standpoint of density and different manufacturers products. The majority of foam systems tested were either 2.5 or 3 lb/ft^3 density foams. In some cases where the manufacturers supplied the coated foam panels, records were not available and it has not been possible to determine what foam was used.

Elastomeric Coating Systems. During the state-of-the-art survey it was determined that a number of generic types of coating systems had already been found to be unsatisfactory for protecting PUF materials against weathering. These types included coatings that were thin in consistency and brittle in nature, such as latex and oil based house paints and many of the cutback asphalt coatings. It was also found that only elastomeric coating systems performed well when applied over PUF. For this reason, with three exceptions, the only protective coating systems included in this investigation are those designed for use on foam, i.e., with rubber-like or elastomeric characteristics. The exceptions include: System 15, a high quality fibrated aluminum-pigmented asphalt; System 21, a cement filled acrylic emulsion; and System 39, a thick rigid cementitious type of topping. These were included as a "control" since these three materials are often used over PUF materials even though their performance records have not been outstanding.

Most generic types of elastomeric coating systems that appeared to have merit for protecting spray-applied PUF materials were included in this investigation (Table 1). Table 1 includes combinations of some of the generic types, such as Systems 3, 4, 7, 9, 16, 19, 23, and 30. The descriptions in Table 1 include the number of coats applied, dry film thicknesses for each coat, total dry film thicknesses, and the foam density utilized in the test panels for each system.

System designations marked "A" indicate that the same coating system was used but the foam density was different. Systems marked "G" indicate that granules were applied in the topcoat. Systems marked "C" indicate that the panels were sprayed with foam and coated by a private contractor.

An additional consideration in the selection of the test systems was the permeability of the coating system. There has always been a controversy in the industry over whether "permeable" or "breathing" or "impermeable" or "nonbreathing" coatings generally perform best as protective coatings for foam. Although there are no firm data supporting a case for either type, it would appear that both are useful under certain conditions. Actually, all of the coatings are permeable to a certain amount of moisture vapor but vary in their degree of permeability. For purposes of this report, coating systems with ratings (ASTM Designation E 96) of less than 1 perm are considered vapor impermeable, and systems with ratings greater than 1 perm are considered vapor permeable. Permeability designations for the various systems are indicated in Table 2.

Field Investigations

In order to determine the performance characteristics of the various elastomeric coated PUF roofing systems, plywood panels were sprayed with PUF, coated, and exposed at three different experimental field weathering sites. Periodically, these experimental panels are inspected and photographed, and small samples are removed and returned to the laboratory for additional study.

Preparation of Experimental Panels. Specimen panels were constructed from 1/2-inch plywood cut to a 2- by 4-foot size. Two 2 x 4's were secured across the 2-foot width of the panels for later use in attaching the experimental panels to the exposure racks. To assure good adhesion of the foam, the wooden panels were primed with one of several different primers. These included: an asphalt roof primer, Federal Specification SS-A-701a; a commercial chlorinated rubber; a Federal Specification chlorinated rubber, TT-P-95; a wash primer, MIL-P-15328; and a commercially available butyl primer. Asphalt primers are not recommended because of their long dry time. Quick drying primers are recommended. After drying, the back sides of the panels and any other exposed wooden surfaces were painted to protect them from weathering.

Following proper curing of the primer, the PUF was spray-applied to the primed surface using a Gusmer Model FF unit. Application was in either two or three lifts to provide approximately 1-1/2 inches of PUF. This gave 2 to 3 ft^2 of foam per pound of the liquid urethane components. The technicians applying the foam exercised great care in properly adjusting the foaming equipment in order to obtain quality foam surfaces, i.e., surface textures as smooth as possible. Very rough surface textures, such as popcorn or treebark, were not acceptable, and any panels having such surfaces were discarded.

Later in the program, some test panels were foamed and coated by coating manufacturers, using their equipment and their coating specifications. To determine the effects of foam density on coating performance, several different densities were used, as indicated in Table 1.

Four panels to be coated were prepared for each of the systems. Three of these were intended for long term exposure at the three experimental sites and the fourth was used to determine selected properties after various periods of weathering at the seashore site. In addition, several panels of both densities of PUF were prepared and were to remain uncoated. Several panels were prepared (foamed and coated) at the same time.

A detailed description of the coating systems and their application is given in Table 1. Trade names and sources of the materials are listed in Appendix A. Coating coverage and thicknesses were determined by spraying the systems on steel panels prior to and during application of the coatings to the foam. Coverage was determined by measuring the wet film thickness with a wet film thickness gage, and dry film thickness was later determined using a magnetic thickness gage. Dry film thicknesses listed in Table 1 were primarily determined with a Peak Scale Lupe on samples cut from the coated foam. Unless noted otherwise, the coating systems were easily applied with a 30-to-1 airless spray unit.

Exposure Sites. One panel of each of the systems described above was exposed at each of three experimental weathering sites. The sites were carefully selected to provide different weathering conditions. The three experimental sites are described below. Panels are inclined at a slope of about 3.5 inches in 12. Initial panels were installed during the summer and fall of 1974 and remained exposed until they were rated as having failed. Systems remain on exposure as long as they perform satisfactorily (up to 12 years - except at the mountain site - see below).

Seashore Site - Port Hueneme, California. This site is a temperate marine atmosphere located along the coast about 60 miles northwest of Los Angeles. The experimental weathering racks shown in Figure 1 are located approximately 200 yards from the surf at an elevation of about 10 feet above sea level.

Desert Site - China Lake, California. This site is a dry, high desert area located about 125 miles northeast of Los Angeles. The exposure racks, shown in Figure 2, are situated on one of the test ranges at the Naval Weapons Center (NWC), China Lake, California, at an elevation of about 2,440 feet.

Mountain Site - Pickel Meadows, California. This site was located at the Marine Corps Mountain Warfare Training Center, Pickel Meadows, California (MCMWTC). This activity is located in the Sierra Nevada mountains about 18 miles west of Bridgeport, California at an elevation of 7,000 feet. The racks are shown in Figure 3. Unfortunately, it was necessary for the test panels to be removed from the racks at the mountain site, sometime around June 1982, in order to construct a new headquarters building.

Performance Characteristics. The performance characteristics of the coated PUF roofing systems were determined at periodic intervals by visual inspections and ratings, and by photomacrographic studies. In addition, physical measurements were made on the uncoated control panels to determine the extent that the foam degrades with time.

Visual Inspections and Ratings. The visual inspections consist of a careful study and rating of the performance characteristics of the coated PUF panels. Since the first signs of deterioration of the PUF roofing systems normally occur in the coatings, the various factors considered relate primarily to coating performance. The performance characteristics that were considered included adhesion, blistering, checking, cohesion, cracking, flaking, peeling, pinholing, and hail damage. Where applicable, performance characteristics covered by ASTM Photographic Reference Standards were used in assigning ratings to the individual characteristics. All of these factors were then considered in assigning the overall performance ratings presented in this report. Ratings were assigned as follows:

10 = Excellent - The system is performing without any noticeable deterioration.

9+ = Very good - Only very minor deterioration of the system.

9-8 = Good - Although the system shows some deterioration, it is not yet serious.

7 = Poor - System deterioration is becoming serious. Remedial action will be required in the near future.

6-0 = Failed - Deterioration of the system has advanced to the point of requiring immediate maintenance.

Photomacrographic Studies. During the inspections, photomacrographic studies were conducted on all of the systems at each site. Photomacrographs were taken of five different spots, about 1 inch by 2 inches in size, on each panel. A template is used so that the same five spots are photographed during each inspection, thus providing a progressive record of coating deterioration. Enlarging of these photomacrographs also provides a record of initial deterioration that is not obvious to the naked eye. Examples of the photomacrographs are presented later in the report.

Foam Degradation Rate Studies. Each time a group of coated PUF experimental roofing panels was placed on exposure at a weathering site, uncoated control panels were also exposed at the same site. They were included to enable determination of foam degradation rates as well as to disclose information on the mechanism of degradation.

The device for determining foam degradation is shown in Figure 4. It consists of a rigid gage reference bar (A), made of aluminum 1 inch thick, which is properly positioned by seating its legs in two positioning pads (B) permanently attached to the supporting 2- by 4-inch cross-piece of each panel. Readings on the specimen are made by inserting a micrometer depth gage into each of 11 holes drilled in the reference bar. In Figure 4, the depth gage is shown in hole 4. Degradation of the foam is determined by noting changes in the distance from the reference bar to the foam surface from reading time to reading time. Before depth gage readings are made, degraded foam is brushed away so that the depth gage is seated on a sound foam surface. The foam degradation rate was determined by dividing the total degradation in inches by the total exposure period in months. Results for exposure times up to 4 years are shown in Table 3 for foams having densities of 2, 2.5, and 3.0 pcf.

Field Tests Conducted by U.S. Bureau of Reclamation for NCEL. At the request of NCEL, the U.S. Bureau of Reclamation (USBR) exposed test panels with selected coating systems at two different sites in Colorado. Details of the study are summarized in Appendix B.

Laboratory Investigations

In addition to the field exposures, selected physical properties were determined on coated and uncoated PUF samples included in the investigation. These properties included: (1) adhesion (2) resistance to wind-driven rain, (3) impact resistance, and (4) tensile properties of free films of the coating systems. Properties (1) through (3) were determined on specimens cut from panels exposed at the seashore site.

Adhesion Properties. The adhesion of the various coatings to the PUF was determined using the NCEL-developed adhesion test method on samples cut from the second set of coated PUF panels exposed at the seashore site. The adhesion properties were determined before exposure and after varying periods up to 4-1/2 years. The test consists of "gluing" a cylindrical probe to the coating and then pulling the probe from the coated specimen in a testing machine, causing the coating to fail either in adhesion or cohesion. Except for the silicones, the probes were glued to the coatings with a polyamide-cured epoxy adhesive. A silicone adhesive was used on the silicone coatings. Ten values were obtained for each coating system and the five highest values were averaged. The testing fixture is shown in Figure 5. Results on those that were determined are presented in Table 4.

The adhesion tests were also employed to determine how long the PUF can be allowed to remain uncoated and exposed to sunlight and weathering without affecting the adhesion of the coating to the foam. Twelve 2- by 4-foot plywood panels containing foam with a density of 2.5 pcf were placed outside at Port Hueneme to weather for periods of 1, 3, 24, 48, and 72 hours, and 9 days before being coated. Six of the panels were coated with the silicone of System 2, while the other 6 were coated with the neoprene-hypalon of System 7. The adhesion properties of these coated PUF systems, determined after being exposed for from 2 months to 4-1/2 years at the seashore site, are presented in Table 5.

Wind-Driven-Rain Resistance. The procedure described in military specification MIL-C-555 was used for this test. Basically, the procedure consists of providing a curtain of water on the coated face of the PUF specimen. This water-curtained surface was then pressurized at 5 psi to simulate the force of a wind-driven rain. The amount of water absorbed is determined by weighing the specimen before and after exposure. Table 6 shows results of wind-driven rain tests made on specimens cut from the second set of panels (exposed at Port Hueneme) before they were exposed and after varying exposure periods up to 4-1/2 years.

Impact Resistance. The impact test device, shown in Figure 6, was similar to that described in Reference 3. The impactor (called TUP in Reference 3) consists of a plastic cylinder with a 1-inch-diameter steel ball at the bottom. Metal shot can be added to the impactor to vary the weight. The impactor was dropped through a plastic pipe with a 1-1/2-inch inside diameter for a distance of 5 feet, at which point the steel ball portion impacted the coated surface of the PUF specimen. Starting with the minimum weight of 160 grams, the impactor weights used were 160, 200, 300, 400, and 500 grams (maximum). Each test was continued until the impactor caused a break in the coating or until the maximum of 500 grams was reached. At least five impacts were made at each impactor weight. Results of these tests are shown in Table 7.

Tensile Properties of Free Films of the Coating Systems. The procedure for determining the tensile properties of coating systems used in this part of the laboratory investigation is described in Reference 6. Glass plates, one surface of which was treated with a release agent, were

placed alongside the experimental foam panels. The protective coatings included in this investigation were applied to the treated glass surface at the same time they were applied to the foam surfaces. Where the system consisted of two coats, both the base coat and top coat were applied to the glass plate. The coating systems were allowed to cure on the glass plates and were then stripped off. Prior to testing, the free films were permitted to equilibrate for at least 7 days in a controlled environment of 50% R.H. and 70°F. They were then cut into strips approximately 2 cm wide with a special cutter and their thickness determined with a micrometer. At least ten specimens were tested to failure and the five highest values for tensile strength and for percent elongation were averaged. Results are listed in Table 8.

Laboratory Tests Conducted by USBR for NCEL

At the request of NCEL, personnel at USBR conducted laboratory tests to determine the glass transition temperature of selected coating systems furnished by NCEL. Results are presented in Appendix B.

RESULTS OF FIELD INVESTIGATIONS

Visual inspection, rating, and photographing of the experimental PUF roofing systems at the three sites have been done at periodic intervals of about 1 year. Because all systems were not exposed at the same time, they do not have ratings for the same length of time. Table 9 shows example data sheets for Systems 1 and 8. Overall performance ratings were determined by giving consideration to each of the coating deterioration factors shown across the top of the sample sheet shown in Table 9.

Results for each of the systems are presented in Table 10. Numerical values shown in Table 10 are the latest ratings on each of the coating systems in the continuing exposure study of the coated PUF panels. Performance evaluations corresponding to the numerical ratings are listed in the footnote to Table 10. Results for the mountain site indicate shorter exposure times because of early removal of the test panels.

Silicones

Catalyzed.

Cement Gray Over Medium Gray. At both the seashore and desert sites, System 1 was rated excellent (10, 10-). Although both panels were susceptible to bird pecks, the panel at the desert site had several more. At the mountain site, System 1 was rated good (9) because of pinholes and moderate cracking. All the silicone panels became very dirty in a relatively short time.

Cement Gray Over Medium Gray With Granules. System 1G was rated excellent (10, 10-) at the seashore and mountain sites, and very good (9+) at the desert site. The panel at the mountain site was downrated slightly because of minor pinholing. The panel at the desert site was downrated slightly because of cracking, breaks in the coating, and hail damage. The granules seem to have minimized the attraction of dirt.

Off-White. System 51 was rated excellent (10) but had been exposed for only 3 months.

Moisture-Curing.

White Over Light Gray. At the seashore site, System 2 was rated good (9). It began to exhibit moderate cracking and checking between 2 and 4 years of exposure and showed several breaks attributed to bird pecking. The severity of the cracking and checking did not worsen in the next 9 years. This silicone panel also became very dirty. System 2 was rated very good (9+) at both the desert and mountain sites. Both panels were downrated slightly due to minor checking and cracking. They also exhibited bird pecks. At the seashore site, System 2A was rated excellent (10-), downrated very slightly due to very minor cracking and bird pecks. At the desert site, System 2A was rated very good (9+), downrated slightly due to minor cracking and bird pecks. System 2A was rated only as good (9) at the mountain site because of moderate cracking and pinholing, along with birdpecking.

White Over Light Gray With Granules. System 2G was rated excellent at all three sites.

Emulsion. At the seashore site, System 29 was rated good (9-). Checking and pinholing, which developed almost immediately, increased in severity over the next 6 years, and there were breaks in the coating along with bird pecks. System 29 was rated very good (9+) at the desert site and exhibited minor checking, cracking, and pinholin At the mountain site, System 29 was rated excellent (10).

Butyl-Hypalons

White Hypalon Over Black Plural-Component Butyl. At the seashore site, System 3 was rated poor (7). This panel exhibited pinholing and cracking of the topcoat which resulted in erosion and peeling of the topcoat from the base coat. System 3 failed (2) at both the desert and mountain sites due to many pinholes that soon became cracks and ended with erosion and flaking of virtually the entire hypalon topcoat.

White Single-Component Hypalon Over Tan Catalyzed Butyl (Systems 4 and 4A). At the seashore location, System 4 was rated excellent (10). System 4, rated good (9) at the desert site, began to show pinholing almost immediately after exposure. The pinholing grew slightly in severity with time, and checking and breaks in the coating also contributed to its lower rating. System 4 was also rated good (8+) at the mountain site. Pinholing and cracking began to develop after about 4 years and increased in severity rapidly, causing many breaks in the coating. There were also several breaks in the coating caused by hailstones. At the seashore site, System 4A was rated poor (7) due to pinholing and cracking which eventually resulted in erosion and peeling of the topcoat from the base coat. System 4A was also rated poor (7) at the desert site. After about 3 years of exposure, checking and pinholing developed which became more severe with time. Cracking and breaks in the coating later contributed to the lower rating. The panel also showed

several bird pecks. At the mountain location, System 4A failed (6). Very dense pinholes were seen all over the panel at the start, but they did not begin to penetrate the coating to the foam until after about 2 years of exposure. Eventually, cracking developed in the coating which exposed the foam in several places. Hailstones also damaged this panel.

White Catalyzed Single-Component Hypalon Over Black Catalyzed Butyl (System 9). At the seashore site, System 9 was rated good (8). After about 2 years, it developed pinholing which became increasingly more severe. Some of the pinholes went through the coating to the foam. System 9 failed (3) at the desert site. For the first 6 months it seemed to do well but then began to show moderately heavy pinholing all over the panel. After 3 years, the pinholing developed into cracks which increased in severity and finally resulted in line-cracking which caused its failure. At the mountain site, System 9 was rated poor (7). After 3 years, it began to exhibit checking and pinholing, the severity of which increased rapidly, followed by cracking of the coating. Some hailstone damage was also noted.

Hypalons

White Single-Component (System-5). At the seashore site, System 5 was rated good (8). Checking and pinholing began after about 2 years and became moderately severe after 5-1/2 years, resulting in some cracking and breaks in the coating. System 5 failed (5) at the desert site. After 3 years of exposure, checking/crazing and pinholing developed which increased in severity rapidly and resulted in serious cracking of the coating. The panel also showed bird pecks. At the mountain site, System 5 was rated good (8-). After 3 years, checking/crazing and pinholing began which increased moderately in severity and resulted in some cracking of the coating.

White Mastic (Systems 12 and 12A). System 12 was rated good (9-) at the seashore site. After about 2 years, pinholing developed, which increased moderately in severity and resulted in moderate cracking of the coating. At the desert site, System 12 was rated poor (7). After 2 years, checking/crazing and pinholing appeared which increased in severity rapidly and resulted in serious cracking. This panel also showed the effects of bird pecking. System 12 was also rated good (8+) at the mountain site. The same checking, cracking, pinholing, and cracking developed here but not as severely as at the desert site.

System 12A was rated very good (9+) at the seashore site, downrated slightly due to moderate crazing. At the desert site, System 12A was rated good (9-). Checking, which began to appear after 1 year, increased significantly over the next 10 years. Pinholing was moderate. Several breaks appeared in the coating, along with bird pecks. System 12A was rated good (8+) at the mountain site. Checking/crazing and pinholing, which began after 2 years, increased in severity moderately over the next 5 years.

Acrylics

White Emulsion (Systems 6, 6A, 20, 31, 43). At the seashore site, System 6 was rated very good (9+), downrated slightly due to light pinholing and checking. System 6 was also rated very good (9+) at the desert site, downrated slightly due to light checking and the effects of bird pecks. System 6 was rated excellent (10-) at the mountain site. Light surface checking and crazing caused a slightly lower rating.

At the seashore site, checking, pinholing, and cracking were moderately heavy in System 6A, resulting in a lower rating of good (9). System 6A was rated very good (9+) at the desert site, marred slightly by checking and bird pecking. Moderately severe checking followed by cracking of the coating resulted in a rating of good (8) for System 6A at the mountain site.

At the seashore site, moderate pinholing caused System 20 to be rated down slightly to very good (9+). At the desert site, System 20 was rated excellent (10-), light pinholing having only a minor effect. Pinholes and blisters caused a lower rating of good (9-) for System 20 at the mountain site.

System 31 was rated excellent (10-, 10, 10) at all three exposure sites. It was rated down very slightly (10-) at the seashore site due to light pinholing.

At the seashore site, System 43 was rated excellent (10), but it had been exposed for only about 2 years.

White Emulsion With White Granules (Systems 6G, 24G). At all three sites, System 6G was rated excellent (10-, 10, 10). At the seashore site, minor blistering caused a slightly lower rating (10-). System 24G was rated excellent at all three exposure sites.

White Emulsion With Gray Granules (Systems 35GC, 36GC). At the seashore location, System 35GC was rated excellent (10). System 36GC was also rated excellent (10-, 10, 10) at all three sites.

Green Emulsion (System 32). At the seashore location, System 32 was rated good (9). Checking, pinholing, and cracking were moderately heavy, resulting in some breaks in the coating. At the desert site, System 32 was also rated good (9). Pinholing, which appeared after 1 year, increased significantly in severity with time. Erosion of the green topcoat was also evident. System 32 was rated excellent (10-) at the mountain site, rated down very slightly due to light pinholing.

White Emulsion Cement-Filled (System 21). At the seashore site, System 21 was rated good (9-). This system is a rigid, cementitious coating highly susceptible to shrinkage cracks. Several cracks developed that ran across the whole panel, but the foam was not yet exposed. At the desert site, System 21 was rated excellent (10-), marred only by minor cracking. Severe checking followed by cracking of the coating caused System 21 to be rated good (8) at the mountain site.

Neoprene-Hypalon

White Single-Component Hypalon Over Black Neoprene (System 7). At the seashore site, System 7 was rated very good (9+). This system was rated down slightly because of pinholes and erosion of the topcoat. At the desert site, System 7 was rated very good (9+). It was rated down slightly due to pinholes and a few breaks in the coating. At the mountain site, System 7 was rated good (9) due to pinholing and cracking.

Butyls

Catalyzed Aluminum-Gray, Aluminum-Pigmented (Systems 8, 8A). At the seashore site, System 8 failed (3) after 2 years due to severe checking and pinholing which resulted in cracking through the coating to the foam. System 8 also failed (5) at the desert site for the same reasons as above. At the mountain site, System 8 was rated good (8), but was affected rather seriously by pinholing and cracking.

At the seashore site, System 8A was rated good (9-) due to moderately severe pinholing and checking which resulted in moderate cracking of the coating. System 8A was rated good (9) at the desert site for the same reasons as above. System 8A showed moderately serious checking, pinholing, and cracking which resulted in a rating of good (8+) at the mountain site.

Chlorinated Rubber

At the seashore site, white over gray System 11 was rated excellent (10-), downrated very slightly due to micropinholing. Due to checking and crazing, System 11 was rated very good (9+) at the desert site. System 11 was rated poor (7) at the mountain site because of checking, cracking, and hail damage.

Fibrated Aluminum-Asphalt

At the seashore location, aluminum over black System 15 was rated excellent (10-), downrated very slightly due to the presence of a few blisters. At the desert site, System 15 was rated good (9-) due to cracking and breaks in the coating. System 15 failed (6) at the mountain site principally due to cracking of the coating and hail damage.

Catalyzed Urethanes

Aluminum-Pigmented (Systems 10, 10A, 17). At the seashore site, System 10 rated poor (7) and developed moderate cracking after about 1 year which became very serious in the next 2 years. After 2 years at the desert site, System 10 began to show severe flaking and spalling and was rated good (8). It looked excellent for the first 2 years but then developed checking and cracking which worsened rapidly.

System 10A failed in the first year at the seashore site due to extremely severe cracking and flaking of the coating which exposed the foam.

At the seashore site, System 17 was rated good (9). It developed checking and pinholing in the second year which increased in severity over the next several years, resulting in some erosion of the topcoat. At the desert site, System 17 was rated good (9-). After the first year, checking and pinholing developed into cracking and some flaking of the coating. System 17 was also rated good (8+) at the mountain site. Pinholing and checking developed in the first year. The checking turned to crazing and cracking.

White Aliphatic Over Aluminum-Gray Aromatic (Systems 13, 13C, 13AC). At the seashore site, System 13 was rated excellent (10). System 13 was rated very good (9+) at the desert site, downrated slightly due to moderate pinholing. At the mountain location, System 13 was rated excellent (10).

System 13C was rated good (9-) at the seashore location. Pinholes that developed in the first 3 years developed into cracks and erosion, exposing the foam in spots. At the desert site, System 13C was rated very good (9+), downrated slightly by pinholing which developed after 4 years but did not increase in severity.

At the seashore site, System 13AC was rated good (9-). Pinholes exhibited in the first 3 years developed into cracks and erosion, exposing the foam. System 13AC was rated good (8-) at the desert location, downrated due to pinholing which eventually penetrated to the foam in several spots. At the mountain site, System 13AC was rated good (9) and exhibited pinholes, later causing cracks which did not penetrate to the foam.

White Aliphatic Over Brown Aromatic (System 38). At the desert site, System 38 was rated very good (9+), marred slightly by moderate checking.

White Aliphatic Over Light Gray Aromatic (System 44). At the seashore site, System 44 was rated excellent (10-), downrated very slightly for light checking. This panel had been exposed for approximately 2 years.

White Aliphatic Over Off-White Aromatic (System 25W). At the seashore location, System 25W was rated good (9). After about 1 year very heavy micropinholing developed, but did not penetrate to the foam in the next 6 years. During the fifth year, severe checking appeared which resulted in a lower rating. At the desert location, System 25W was also rated good for the same reasons as at the seashore site. At the mountain site, System 25W was rated excellent (10-), downrated slightly due to minor checking and pinholing.

White Aliphatic Over Gray Aromatic (Systems 52, 53). At the seashore site, Systems 52 and 53 were both rated excellent (10), although exposed for only 3 months.

Gray Aliphatic Over Off-White Aromatic (System 25GY). At the seashore site, System 25GY was rated good (9). Micropinholing and checking became widespread resulting in a lower rating. At the desert and mountain sites, System 25GY was rated excellent (10).

Off-White Aromatic Over Black Aromatic (System 18). At the site, System 18 was rated very good (9+), downrated somewhat due to heavy surface crazing. At the desert site, System 18 was rated excellent (10-), downrated very slightly because of surface crazing. At the mountain site, System 18 was rated excellent (10).

White Aromatic Over Aluminum-Gray Aromatic (System 37). At the seashore site, System 37 was rated very good (9+), downrated slightly due to checking and pinholing. At the desert site, System 37 was rated good (9) because the topcoat had begun to erode and checking had reached the stage of incipient cracking. At the mountain site, System 37 was rated very good (9+), downrated slightly due to checking.

White Aliphatic Over Gray Aromatic (System 46). At the seashore site, System 46 was rated excellent (10-) and exhibited slight checking. It was exposed for about 2 years.

Off-White Aromatic With Green Granules (System 26G). At the seashore site, System 26G was rated good (9) because serious checking was causing the topcoat to deteriorate and the granules to blow off. At both the desert and mountain sites, System 26G was rated excellent (10).

Moisture-Curing Urethanes

Gray Aromatic (Systems 14, 14A). At the seashore site, System 14 failed (5). In less than 1 year checking/crazing and erosion of the topcoat had developed. In about 3 years the topcoat was deteriorating, chalking heavily, and flaking. System 14 also failed (5, 4) at both the desert and mountain sites due to widespread line checking, cracking, and flaking. System 14A failed (3, 5) at the seashore and mountain sites for the same reasons that System 14 failed. At the desert site, System 14A was barely rated good (8-) due to checking, crazing, and minor flaking.

Aluminum Aromatic (System 48). At the seashore site, System 48 was rated excellent (10) after about 2 years of exposure.

Tan Aromatic With Gray Granules (System 22G). At the seashore site, System 22G was rated good (8). It was rated excellent through the first 5-1/2 years, but in the next 2 years the topcoat began to erode, allowing granules to blow away. At both the desert and mountain sites, System 22G was rated excellent (10, 10).

Brown Aromatic (System 34). At the seashore site, System 34 was rated good (9), downrated somewhat due to pinholing and erosion of the topcoat.

Aluminum-Pigmented Aromatic With Granules (System 27G). At the seashore site, System 27G was rated good (9-). It was rated excellent through the first 5 years, but then checking and erosion of the topcoat became serious. At both the desert and mountain sites, System 27G was rated excellent, but the panels there had not been exposed as long as the ones at the seashore site.

Aluminum Aromatic Over Aromatic With Gray Granules (System 28G). At all three sites System 28G was rated excellent (10, 10, 10).

White Aliphatic Over Brown Aromatic (System 33). At the seashore location, System 33 was rated very good (9+). After the first 2 years, pinholing and light cracking developed.

White Aliphatic Over Black Aromatic (System 54). At the seashore site System 54 was rated excellent (10) but had been exposed for only 3 months.

White Aliphatic Over Aluminum Aromatic (System 49). After exposure of almost 2 years, System 49 was rated very good (9+), downrated slightly due to pinholing and checking.

Aluminum-Pigmented Aliphatic Over Aluminum-Pigmented Aromatic (System 42). At the seashore location, System 42 was rated excellent (10) after being exposed for a little over 2 years.

Urethane-Hypalons

White Catalyzed Single-Component Hypalon Over Aluminum-Gray Aromatic Urethane (Systems 16C, 16AC). At the seashore site, System 16C was rated excellent (10-), downrated very slightly due to light pinholing. At the desert site, System 16C was rated good (9-). After 5-1/2 years, minor pinholing became serious, resulting in several cracks in the coating along with spalling. System 16C was also rated good (9-) at the mountain site because pinholes had begun to penetrate to the foam. At the seashore site, System 16AC was rated down slightly to very good (9+) due to deepening pinholes and some erosion of the topcoat. At the desert site, System 16AC was rated poor (7). Pinholing which developed early became increasingly serious, followed later by checking and breaks in the coating. At the mountain site, System 16AC was rated poor (9-), downrated because pinholes began to penetrate to the foam.

Urethane-Silicone

White Moisture-Curing Silicone Over Black Catalyzed Aromatic Urethane (System 19). At the seashore site, System 19 was rated very good (9), downrated slightly because of penetrating pinholes and some lack of adhesion. When there was a minor break in the topcoat, the topcoat could be peeled off the base coat rather easily. At the desert site, System 19 was rated good (9), showing pinholing and serious loss of adhesion of topcoat to base coat. At the mountain site, System 19 was rated good (9-). Pinholing, loss of adhesion, and cracking contributed to the lower rating.

White Moisture-Curing Silicone Over Tan Moisture-Curing Aromatic Urethane (System 23). At the seashore site, System 23 was rated excellent (10). At the desert site, System 23 was rated very good (9+), downrated slightly due to minor loss of adhesion of topcoat. At the mountain site, System 23 was rated excellent (10).

Neoprene Asphalt-Acrylic Emulsion

White Acrylic Emulsion Over Black Neoprene Asphalt (System 30). At the seashore site, System 30, rated good (9), showed moderate checking, pinholing, blistering, and erosion in the first 2 years which became more serious in the next 5 years. At the desert site, System 30 was rated good (9) because of checking/crazing, cracking, and some flaking in the first year which worsened over the next 6 years. System 30 was rated excellent (10-) at the mountain site. Minor checking and pinholing noted in the first year did not worsen over the next 3 years. The panel at the mountain site was exposed for a little over half as long as the panels at the other sites.

Rapid-Cure Urethane

White Catalyzed Aliphatic Over Brown Rapid-Cure Aromatic (Systems 40, 41, 45, 50). At the seashore site, Systems 40, 41, and 50 were rated excellent (10). System 45 was also rated excellent (10-) but was marred slightly due to slight checking. Note that these systems were exposed for moderately short times from almost 3 years down to only 3 months.

White Catalyzed Aromatic/Aliphatic Over Black Rapid-Cure Aromatic (System 47). At the seashore site, System 47 was rated excellent (10-), marred very slightly by minor checking. It was exposed for about 2 years.

Rigid Cementitious

White Cementitious Over Black Elastomeric (System 39). At the seashore site, System 39 was rated excellent (10-), downrated very slightly due to the many small cracks expected with this type of coating. The cracks have widened slightly, but the foam does not seem to be degrading.

Performance of Coating on Foam Aged Prior to Coating

Ratings for panels where the foam was aged before the coating was applied are presented in Table 11. For System 2, a moisture-curing silicone, the effects of allowing the foam to age seem negligible except for the panel aged for 72 hours. Since the principal deterring factor in this panel was heavy pinholing, it is probable that the spraying of the coating was not done as well as it was on the other panels in the series. For System 7, a neoprene-hypalon, the effects of the aging of the foam prior to coating also seem negligible.

Field Studies Conducted by USBR

Results of the field exposure studies conducted by USBR for NCEL on PUF panels with selected coating systems are summarized in Appendix B.

Photomacrographic Studies

As stated above, photomacrographs were taken for several years of the study to determine, on a closeup basis, the effects of weathering upon the coatings. For purposes of brevity in the report, photomacrographs were selected for four of the coating systems; two that performed very well (Systems 1 and 13) and two that failed (Systems 8 and 14).

Photomacrographs of System 1, a catalyzed silicone, are shown in Figure 7.

Photomacrographs of System 13, a catalyzed urethane, are presented in Figure 8.

Photomacrographs of System 8, a catalyzed butyl, are presented in Figure 9.

Photomacrographs of System 14, a moisture-curing urethane, are shown in Figure 10.

Foam Degradation Rate Studies

Degradation per year for foams with densities of 2.0, 2.5, and 3.0 pounds per ft^3 are shown in the last column of Table 3 at all three exposure sites. At each location, degradation varied inversely with foam density, i.e., the more dense the foam, the lower the degradation. Generally, degradation resulting from exposure at the mountain site (elevation 700 ft) was higher than at the desert site (elevation 2,440 ft), and degradation there was higher than at the seashore site. Ultraviolet concentration, which increases directly with elevation, is believed to be the principal factor.

RESULTS OF LABORATORY STUDIES

Adhesion Properties

As noted earlier, a second set of panels of the coating systems was exposed at the seashore site for determining several properties including the adhesion characteristics. These panels were arranged so that they could be removed periodically from the exposure racks, samples cut for the selected property tests, and the remaining part of the specimens returned to the rack for additional exposure. The adhesion properties of the coated PUF samples are given in Table 4.

In addition to the adhesion properties of the coating-foam systems, Table 4 also describes the mode of failure, i.e., whether the coating lost adhesion to the foam or to itself, or whether failure occurred cohesively within the coating or foam. As might be expected, a number of the systems showed more than one mode of failure. However, failure in the majority of the systems tested occurred cohesively within the foam (failure mode 6). This would be expected with coating systems having good adhesion between coating and foam. Only a few of the failures resulted from loss of adhesion of the coating to the foam (failure mode 3).

Silicones. Referring to Table 4, Systems 1 and 1G (catalyzed silicone and catalyzed silicone with granules) and Systems 2 and 2A (moisture-curing silicones) showed cohesive failures in the foam (failure mode 6). On the other hand, System 2G, moisture-curing silicone with granules, exhibited cohesive failure in the topcoat (failure mode 4) and adhesive failure of granules to coating. After 4-1/2 years of exposure, the silicones showed an average adhesion strength of 10.6 kg/cm^2.

Butyl-Hypalons. Systems 3 and 4 showed mostly cohesive failures in the base coat (failure mode 5) and adhesive failures of coating to foam surface (failure mode 3). System 9 failures were principally in the foam, indicating increasingly improving adhesion properties as time of exposure increased. The average adhesion strength of the butyl-hypalons was 11.8 kg/cm^2.

Hypalons. Systems 5, 12, and 12A all showed cohesive failures in the foam, indicating good adhesion properties. Average adhesion strength of the hypalons was 14.6 kg/cm^2.

Acrylics. For the most part, the acrylics showed cohesive failures in the foam. The exceptions were Systems 31 and 35 which indicated adhesive failure between topcoat and base coat. The average adhesion strength of the acrylics after 4-1/2 years was 18.4 kg/cm^2.

Neoprene-Hypalon. System 7 exhibited cohesive failure in the foam. Adhesion strength of the neoprene-hypalon was 17.8 +kg/cm^2.

Butyl. System 8 showed cohesive failure in the base coat and had and adhesion strength of 11.1 kg/cm^2.

Chlorinated Rubber. Cohesive failure in the foam was observed in System 11, while the adhesion strength was 17.8 kg/cm^2.

Fibrated Aluminum-Asphalt. System 15 showed cohesive failure in the topcoat and adhesion strength of 8.3 kg/cm^2.

Urethanes. Of the catalyzed urethanes, Systems 10, 10A, 13, 13AC, and 18 exhibited cohesive failures in the foam (failure mode 6) System 17 showed adhesive failure between topcoat and base coat. Systems 25 and 26G had cohesive failures in the topcoat. Average adhesion strength of the catalyzed urethanes was 13.0 kg/cm^2. Among the moisture-curing urethanes, Systems 14 and 14A showed cohesive failures in the topcoat, System 27G exhibited cohesive failure in the foam, and Systems 22G and 28G showed adhesive failure of granules to coating. Average adhesion strength for the moisture-curing urethanes was 15.8 kg/cm^2.

Urethane-Hypalons. System 16AC, catalyzed urethane-hypalon, showed cohesive failure in the foam and an adhesive strength of 12.0 kg/cm^2.

Urethane-Silicones. Systems 19 and 23 showed adhesive failure between topcoat and base coat. Average adhesion strength was 5.4 kg/cm^2.

Acrylic Emulsion Over Neoprene Asphalt. System 30 exhibited adhesive failure between topcoat and base coat and had an adhesive strength of 6.0 kg/cm^2.

Table 5 lists adhesion properties of System 2 (moisture-curing silicone) and System 7 (neoprene-hypalon) on panels aged prior to coating. For the most part, System 2 panels showed adhesive failures of coating to foam surface, particularly in tests on panels which were aged more than 3 hours before coating. On the other hand, System 7 panels showed cohesive failure in the foam regardless of the foam age when coated.

Wind-Driven Rain Resistance

Table 6 shows results of wind-driven rain tests on coated specimens.

Silicones. Except for System 1G, the silicones averaged about 1 gram of weight gain. The granules on System 1G may have absorbed extra moisture.

Butyl-Hypalons. The relatively poor quality of the coating materials in System 3 (see Table 12) probably accounts for the higher absorption of water. Weight gain in System 9 was not consistent over the test period, so a loss in weight is questionable. Note that the butyl-hypalons are considered to be vapor impermeable.

Hypalons. The hypalons are also vapor impermeable but gained slightly more weight than the silicones that are vapor permeable. Weight gain for System 12 seems rather high and inconsistent and is therefore unreliable. Excluding System 12, weight gain in the hypalons averaged 1.8 grams.

Acrylics. System 6G showed excessive weight gain after 4-1/2 years and is inconsistent with the previous readings. Excluding System 6G, the weight gain of the acrylics averaged 3.7 grams.

Urethanes. Failure of System 10A in the exposure tests (Table 12) indicates that the system was susceptible to admitting water and may account for the extremely high weight gain. The granules in System 22G may have absorbed some extra water over the last year. The poor showing of System 10 in the exposure tests (Table 12) may account for the jump in weight gain in the last period. Excluding Systems 10A and 22G, weight gain in the urethanes averaged 3.9 grams. The urethanes, as a group, seem to have gained more weight than the other groups, yet the urethanes performed very well in the exposure tests. The significance of the wind-driven rain test seems in question from these tests.

Impact Resistance

The coating is considered to have failed the impact test when it is ruptured. At the point of rupture, the weight of the impactor is recorded. This test was run both before samples had been exposed and after they had been exposed for varying periods up to 4-1/2 years. The impact test

results may indicate the resistance of the coated PUF roofing systems to damage by hailstones and, to some extent, by foot traffic. Both can cause damage to a system with low impact resistance. Results of impact tests are presented in Table 7.

A summary of the average impact strengths of coating systems by type after 4-1/2 years of exposure is shown below.

Coating System Type	Average Impact Strength (grams)
Urethane-Silicones	800
Urethanes	618
Urethane-Hypalons	550
Neoprene-Hypalons	500
Acrylics	473
Neoprene-Asphalt/Acrylic Emulsion	400
Silicones	381
Chlorinated Rubber	260
Butyl	250
Fibrated Aluminum-Asphalt	129

According to the results, the urethane-silicones, the urethanes, and the urethane-hypalons should have the highest resistance to damage by hailstones or foot damage. Since the fibrated aluminum-asphalt is not an elastomer, it is not surprising that its impact strength is the lowest of all the other systems.

Tensile Properties of Free Film

Free films of the total coating systems, base coat and topcoat, were prepared at the same time as the exposure panels. The free films were stripped from the glass plates where they had been applied and, after curing times of 3, 6, and 12 months under ambient laboratory conditions, were cut to size and tested to failure in tension. Results are presented in Table 8 for tensile strength in grams per square millimeter and elongation in percent. Not all systems were tested, but enough were tested to show the effects of aging in the laboratory on tensile strength. While there are some variations, in most cases tensile strengths increased and percent elongation decreased as the cure time increased. This same trend is also typical of conventional paint systems (Ref 6).

High tensile properties for coating systems for PUF are believed to be of primary importance because high tensile strength and high elongation insure a coating with good flexibility. Good flexibility is required to enable a coating to accommodate the rather large expansions and contractions that occur when PUF is subjected to vicious temperature cycling.

A summary of the average tensile strengths and elongations of coating systems by type after 12 months of curing is shown below.

Coating System Type	Tensile Strength (gm/mm^2)	Elongation (%)
Urethanes	431	749
Neoprene-Hypalons	387	251
Silicones	294	328
Hypalon	203	292
Chlorinated Rubber	190	104
Urethane-Silicone	177	721
Butyl-Hypalon	130	157
Acrylics	88	268
Butyl	60	91

The urethanes had the highest average tensile strength as well as the highest percent elongation. Neoprene-hypalon and silicones were next in terms of tensile strength. Urethane-silicone also had a relatively high elongation. Referring to Table 10, the urethanes as a group did fairly well in performance as did the neoprene-hypalon, silicones, and acrylics. Except for the acrylics, these observations seem to link high tensile strength with good coating performance. Because there are some notable exceptions, there does not seem to be any iron-clad relationship between tensile strength/elongation and coating performance on exposure.

Glass Transition Temperature (USBR)

Results of tests to determine the glass transition temperature of selected coating systems are summarized in Appendix B.

DISCUSSION OF TEST RESULTS

Coating Systems That Performed Best at All Three Exposure Sites

Coating systems with excellent or very good ratings at all three sites after at least 3 years of exposure are shown in Table 12. Of the silicones, only the two with granules were rated excellent to very good at all three sites: System 1G (catalyzed with granules), and System 2G (moisture-curing with granules). Both System 1 and System 2 (the same coating systems without granules) performed well at two of the three sites, as did Systems 2A and 29 (Table 10).

Of the nine acrylics that had been exposed for more than 3 years, five were rated excellent or very good at all three sites, and three of those had granules. Systems 6G and 24G had white granules and System 36GC had gray granules, so the color of the granules is not significant.

Of the 16 catalyzed urethanes studied, only two were rated excellent or very good: System 13, an Aliphatic over an aromatic, and System 18, an aromatic over an aromatic. Of the 11 moisture-curing urethanes studied, only one was rated excellent or very good: System 28G, aluminum aromatic over aromatic with granules. It is highly probable that the granules enabled the moisture-cured urethane to

perform satisfactorily. System 23 utilized a combination of a moisture-curing aromatic urethane topped by the moisture-curing silicone of System 2. Thus, System 23 combines the relatively high tensile strength of urethane and the excellent weathering characteristics of the silicone.

Coating Systems That Performed Best at Each Site

Table 13 lists those coatings that performed best at each site. For locations similar to the seashore site used in this study (mild summers, mild winters, and relatively high humidity) several of the systems would provide quite satisfactory coatings for PUF. One would have a choice of several silicones, one butyl-hypalon, several acrylics, a neoprene-hypalon, a chlorinated rubber, a fibrated aluminum-asphalt, several urethanes, two urethane-hypalons, a urethane-silicone, and a rigid cementitious. NCEL personnel have inspected many roofs with an aluminum-asphalt or cutback asphalt coating over PUF. Very few of them had lasted more than a year or two before becoming greatly distressed and in need of recoating. Since aluminum asphalts, such as System 15, have little tensile strength (Table 8), they cannot withstand the rather high tensile stresses developed by the severe temperature changes in a full-size roof. Once the aluminum-asphalt cracks, it soon begins to flake and spall and the exposed foam begins to degrade. It should also be noted that System 15 only did very well at the seashore site where the temperature changes are not very severe. In addition, the small 2- by 4-foot panels used in this study were not large enough to develop high temperature stresses that are present on temperatures found on roofs.

At locations similar to the desert site used in this study (hot summers and cold nights in winter but mild days), several systems could be expected to provide quite adequate coatings for PUF, as shown in Table 13. Several urethanes would be more than adequate in the seashore climate, along with a urethane-silicone and the neoprene-asphalt/acrylic emulsion. Many of the same coating systems acceptable at the desert-type location would also be acceptable at a mountain-type location-moderate summers, cold winters with heavy snow, and relatively low humidity.

Effects of Exposure Site on Performance Rating

For most of the coating types, Figure 11 shows the effects of exposure site on performance rating. For the silicones, the seashore site was worst for Systems 2 and 29, and for Systems 1 and 2A, the mountain site was worst. For the neoprene-hypalon, the mountain site was worst. For the butyl, both seashore and mountain ratings are lower. For butyl-hypalons, the mountain site was worst for Systems 4 and 4A but not for System 9. For the hypalons, the desert site was worst for System 5 and 12, and there was a trend that way for System 12A. For the chlorinated rubber and the aluminum-asphalt, the mountain site was worst. For the acrylics, the seashore site was worst for Systems 31 and 6G and the mountain site was worst for Systems 6A and 20.

For catalyzed urethanes, the seashore site was worst for Systems 25GY, 18, and 26G; the desert site was worst for Systems 13, 13AC, and 37 and the mountain site was worst for System 17. For moisture-cured urethanes, the seashore site was worst for Systems 22G and 27G.

For urethane-hypalons, the desert and mountain sites were low for System 16C and the mountain site was worst for System 16AC. In these systems, the topcoat is hypalon and there is a similarity between the effects of exposure site on these systems and the hypalons. For the urethane-silicones, the mountain site was worst for System 19, and the desert site was worst for System 23. For System 30, the neoprene asphalt-acrylic emulsion, the seashore and desert sites were worse.

The relationships illustrated in Figure 11 indicate that the effects of exposure site on the performance of the coating systems in this study are inconsistent and inconclusive.

Effects of Foam Density on Coating Performance

Table 14 shows the effects of foam density on coating performance. Other things being equal, higher foam density is reputed to make the foam-coating system more resistant to foot and hailstone damage as well as provide a somewhat smoother foam surface for the coating. Such improvements should also enhance the coating system performance. Table 14 indicates that the effects of foam density on performance are not consistent. Higher foam density did not help the performance of Systems 14, 10, 13, and 16. It did help Systems 8 and 12, but improved the performance of Systems 14 at the desert and mountain sites and System 2 only at the seashore site. The apparent conclusion from these observations is that higher foam density did not consistently improve coating performance. However, it should be noted that there was no foot traffic on the panels and the incidence of hail storms at the mountain site was very low. As a result, these physical factors had little influence on the performance of these systems.

Influence of Physical Properties of Coating Systems on Field Performance

The ranking of the physical properties of the top twenty of the coating systems by system number and type is shown in Table 15. Ranking, in terms of optimum property, was taken from Table 4 for adhesion, Table 6 for water weight gain, Table 7 for highest impact strength, and Table 8 for tensile strength and elongation. To determine the significance, or lack of it, of physical properties on field performance, comparisons should be made between Tables 12 and 15.

Table 16 was compiled by comparing the listing of coating systems that showed excellent or very good performances in Table 12 with the listings in Table 15. Not many of the coating systems that performed best appear in the top twenty of each of the physical properties. Adhesion has the most represented, but several of the best systems were not tested for tensile strength or elongation in effect. There appears to be little correlation between laboratory tests and field performance, i.e., the individual physical properties do not seem to directly and consistently influence field performance.

Exposure Tests Conducted by USBR

Below is a summary of the results at the Denver site in Table B-1 of Appendix B.

USBR Rating	Denver Site
Excellent	System 38 - Urethane
Good	System 6 - Acrylic
	System 31 - Acrylic
	System 13 - Urethane
Fair	System 2 - Silicone
	System 29 - Silicone
	System 9 - Butyl-Hypalon
	System 35 - Acrylic
Poor	System 15 - Aluminum-Asphalt

Comparison of the above results with those in Table 12 reveal that several of the coating systems are found in both lists. Systems 6 (acrylic), 31 (acrylic), and 13 (urethane), rated good by USBR, are also in the list of Table 12. System 15 (aluminum-asphalt), rated poor by USBR, does not appear in the listing of Table 12. NCEL tests (Table 10) showed that System 15 performed well only at the seashore site.

Results at the Greeley site shown in Table B-1 of Appendix B are more difficult to compare with NCEL results because no overall evaluation was expressed and because the time of exposure was only 1 year. USBR found the same susceptibility of silicones to damage by bird pecks as NCEL did. System 15 (aluminum-asphalt) experienced serious hail damage which was expected due to its low tensile strength, low impact strength, and nonelastomeric nature.

Glass Transition Tests by USBR

Three-year glass transition temperature (T_g) by the DSC method for System 6, an acrylic, indicate that this material would become brittle at 50°F (Table B-2 of Appendix B). If this measurement is correct, System 6 could be susceptible to serious damage at temperatures below 50°F. This material (System 6) was based on earlier acrylic raw materials that tended to become brittle with aging. Currently available 100% acrylic coatings do not generally embrittle with aging as shown by the other two acrylics listed in Table B-2 of Appendix B. System 15 (an aluminum-asphalt) shows a T_g of 7°F, and System 38 (a urethane) has a T_g of 12°F.

Foam Degradation Studies

Foam degradation per year for foam densities of 2.0, 2.5, and 3.0 pcf in Table 3 vary from 0.14 inch per year for density of 2.0 pcf at the seashore site to about 0.23 inch per year for the same density at the mountain site. Foam degradation rates decreased significantly as the density increased. At the seashore site, the degradation rate of foam with a density of 3.0 pcf was about two-thirds as much as that for the 2.0 pcf, while at the mountain site, the rate of the 3.0 pcf foam was about half that of the 2.0 pcf. Similar results were found at the desert site. Increasing ultraviolet concentration accounts for the higher degradation rates at the desert and mountain sites. It is easy to see that uncoated PUF 2 inches thick when sprayed could be reduced to as little as 1-inch thick after 5 years of exposure.

FINDINGS AND CONCLUSIONS

1. Eleven of the coating systems included in this study were rated excellent or very good in performance at all three of the exposure sites, as summarized below. They are not listed in order of performance.

Coating Type	System	Comments
Silicone	1G	Catalyzed cement gray over medium gray, granules
Silicone	2G	Moisture-curing: white over light gray, granules
Acrylic	6	White emulsion
Acrylic	6G	White emulsion, white granules
Acrylic	31	White emulsion
Acrylic	24G	White emulsion, white granules
Acrylic	36GC	White emulsion, gray granules
Urethane	13	Catalyzed: white aliphatic over gray aromatic
Urethane	18	Catalyzed: off-white aromatic over black, aromatic
Urethane	28G	Moisture-curing: aluminum aromatic over aromatic, granules
Urethane/ Silicone	23	White moisture-curing silicone over tan moisture-curing aromatic urethane

2. Six of the above eleven coating systems had granules, indicating the importance of using granules in the coating system.

3. Several of the coating systems had performance ratings of excellent or very good at one or two of the sites but not at all three. For a climate similar to one of the sites where they performed well, they would be quite suitable there.

4. The effects of exposure site on field performance of the coating systems were inconsistent and inconclusive.

5. Higher foam density did not consistently improve the performance of coating systems. Foam densities used were 2.0, 2.5, and 3.0 pcf.

6. The eleven coating systems that were rated excellent or very good at all three sites did not consistently have optimum physical properties such as adhesion, water absorption, impact strength, tensile strength, and elongation. On the other hand, several of the coating systems that ranked relatively high in terms of physical properties did not do very well in terms of performance.

7. Foam degradation studies reveal the absolute necessity of coating PUF to protect it from ultraviolet radiation which can cause as much as 0.2 inch of degradation per year.

RECOMMENDATIONS

1. Eleven of the 54 coating systems used in this study are recommended for coating PUF at any and all locations. They are listed in the first item of "Findings and Conclusions."

2. Any PUF density up to 3.0 pcf is recommended for roofing systems. If heavy foot traffic or hail is expected, the higher densities with a minimum compressive strength of 40 psi are recommended.

3. Although the effects of physical properties on performance were inconclusive, coating systems with relatively high impact strength, tensile strength, and elongation are recommended for protection against hailstones, foot traffic, and extreme temperature changes.

4. All PUF roofing systems should be protected with a proven elastomeric coating system.

5. To further establish the long-time efficacy of coating systems for PUF, this study should be continued.

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Table 1. Description of Sprayed Polyurethane Foam Roof Systems

System Number	Coating System Designation and Color	No. of Coats	Dry Film Thickness (mils)	Total (mils)	Foam Density (lb/ft^3)
1	Catalyzed silicone				
	Base coat: plural component, medium gray	1	13.5	20.5	2.0
	Topcoat: plural component, cement gray	1	7.0		
1G	Catalyzed silicone with granules				
	Base coat: plural component, medium gray	1	13.5	20.5	2.0
	Topcoat: plural component, cement gray	1	7.0		
2	Moisture-curing silicone				
	Base coat: light gray	1	5.0	23.5	2.0
	Topcoat: white	1	18.5		
2A	Moisture-curing silicone				
	Base coat: light gray	1	8.5	16.0	2.5
	Top coat: white	1	7.5		
2G	Moisture-curing silicone with granules				
	Base coat: light gray	1	20.0	30.0	3.0
	Topcoat: white, gray granules	1	10.0		
3	Catalyzed butyl/hypalon				
	Base coat: plural-component butyl, black	1	13.0	18.0	2.0
	Topcoat: catalyzed hypalon, white	1	5.0		
4	Catalyzed butyl/hypalon				
	Base coat: catalyzed butyl, tan	1	14.0	21.0	2.0
	Topcoat: single-component hypalon, white	1	7.0		
4A	Catalyzed butyl/hypalon				
	Base coat: catalyzed butyl, tan	1	14.0	21.0	2.5
	Topcoat: single-component hypalon, white	1	7.0		

Table 1. Continued

System Number	Coating System Designation and Color	No. of Coats	Dry Film Thickness (mils)	Total (mils)	Foam Density (lb/ft^3)
5	Hypalon mastic, single component	1		16.5	2.0
6	Acrylic emulsion	2		41.0	2.0
6A	Acrylic emulsion	1		34.0	2.0
6G	Acrylic emulsion, with white granules	2		100.0	
7	Neoprene/hypalon				
	Base coat: single-component neoprene, black	3	9.0		
	Topcoat: single-component hypalon, white	2	13.0	22.0	2.0
8	Catalyzed aluminum-pigmented butyl, aluminum gray	2		26.0	2.0
8A	Catalyzed aluminum-pigmented butyl, aluminum gray	2		26.0	2.5
9	Catalyzed butyl/hypalon				
	Base coat: catalyzed butyl, black	1	15.5	22.0	2.0
	Topcoat: single-component hypalon, white	1	6.5		
10	Catalyzed aluminum-pigmented, hydrocarbon modified urethane, aluminum	1		26.0	2.0
10A	Catalyzed aluminum-pigmented, hydrocarbon modified urethane, aluminum	1		20.0	2.5
11	Chlorinated rubber				
	Base coat: gray	1	14.0	26.0	2.0
	Topcoat: white	1	12.0		
12	Hypalon mastic, white	2		33.0	2.0
12A	Hypalon mastic, white	2		29.0	2.5

Table 1. Continued

System Number	Coating System Designation and Color	No. of Coats	Dry Film Thickness (mils)	Total (mils)	Foam Density (lb/ft^3)
13	Catalyzed urethane				
	Base coat: aromatic, aluminum-gray	1	15.0		
	Topcoat: aliphatic, white	1	8.5	23.5	2.0
13AC	Catalyzed urethane				
	Base coat: aromatic, aluminum-gray	1	6.0	11.0	3.0
	Topcoat: aliphatic, white	1	5.0		
13C	Catalyzed urethane				
	Base coat: aromatic, aluminum-gray	1	10.0	15.0	2.0
	Topcoat: aliphatic, white	1	5.0		
14	Moisture-curing aromatic urethane, gray	1		42.0	2.0
14A	Moisture-curing aromatic urethane, gray	2		39.0	2.5
15	Fibrated aluminum-asphalt				
	Base coat: fibrated asphalt, black	1	22.0	44.0	2.0
	Topcoat: fibrated aluminum-asphalt, aluminum	1	22.0		
16C	Catalyzed urethane/hypalon				
	Base coat: catalyzed aromatic urethane, aluminum-gray	1	10.0	15.0	2.0
	Topcoat: single-component hypalon, white	1	5.0		
16AC	Catalyzed urethane/hypalon				
	Base coat: catalyzed aromatic urethane, aluminum-gray	1	16.0	19.0	3.0
	Topcoat: single-component hypalon, white	1	3.0		
17	Catalyzed aluminum-pigmented, hydrocarbon-modified urethane				
	Base coat: hydrocarbon-modified urethane, black	1	18.0		
	Topcoat: aluminum-pigmented hydrocarbon-modified urethane, aluminum	1	10.0	28.0	3.0

Table 1. Continued

System Number	Coating System Designation and Color	No. of Coats	Dry Film Thickness (mils)	Total (mils)	Foam Density (lb/ft^3)
18	Catalyzed urethane				
	Base coat: aromatic urethane, black	1	25.0		
	Topcoat: aromatic urethane, off-white	1	35.0	60.0	3.0
19	Catalyzed urethane/silicone				
	Base coat: catalyzed aromatic urethane, black	1	27.0	37.0	3.0
	Topcoat: moisture-curing silicone, white	1	10.0		
20	Acrylic emulsion, white		2		30.0
21	Cement-filled acrylic emulsion, white	1		50.0	2.5
22G	Moisture-curing aromatic urethane, tan, w/gray granules	2		50.0	3.0
23	Moisture-curing urethane/silicone				
	Base coat: moisture-curing aromatic urethane, tan	2	40.0	47.0	3.0
	Topcoat: moisture-curing silicone, white	1	7.0		
24G	Acrylic emulsion, white, with embedded granules	2		60.0	2.5
25	Catalyzed urethane				
	Base coat: aromatic urethane, off-white	2			
	Topcoat: aliphatic urethane; white applied to one-half of panel, gray applied to other half	1		45.0	2.0
26G	Catalyzed aromatic urethane, off-white, w/green granules	3		56.0	2.0
27G	Moisture-curing aluminum-pigmented, aromatic urethane	2		25.0	
28G	Moisture-curing urethane with granules				
	Base coat: aromatic	1	15.0		
	Topcoat: aromacic, aluminum-gray, with gray granules	1	10.0	25.0	

Table 1. Continued

System Number	Coating System Designation and Color	No. of Coats	Dry Film Thickness (mils)	Total (mils)	Foam Density (lb/ft^3)
29	Water-based silicone	2		14.0	3.0
30	Neoprene-asphalt/acrylic emulsion				
	Base coat: neoprene-asphalt emulsion, black	1	90.0		
	Topcoat: acrylic emulsion, white	1	17.0	107.0	3.0
31	Acrylic emulsion, white	2		40.0	2.0
32	Acrylic emulsion, green	2		23.0	2.0
33	Moisture-curing urethane				
	Base coat: aromatic, brown	2			
	Topcoat: aliphatic, white	1	10.0		
34	Moisture-curing aromatic urethane, brown	2		140.0	
35GC	Acrylic emulsion, white, with gray granules	2		30.0	
36GC	Acrylic emulsion, white, with gray granules	2		35.0	2.5
37	Catalyzed aromatic urethane				
	Base coat: aluminum-gray	1	10.0	14.0	
	Topcoat: white	1	4.0		
38	Catalyzed urethane				
	Base coat: aromatic, brown	2	20.0	25.0	3.0
	Topcoat: white	1	5.0		
39	Rigid cementitious, white				
	Base coat: elastomeric, black	1		500-	
	Topcoat: white cementitious	1		700	

Table 1. Continued

System Number	Coating System Designation and Color	No. of Coats	Dry Film Thickness (mils)	Total (mils)	Foam Density (lb/ft^3)
40	Catalyzed rapid-cure urethane				
	Base coat: rapid-cure aromatic, brown	1	75.0		
	Topcoat: aliphatic, white	1	7.0	82.0	2.0
41	Catalyzed rapid-cure urethane				
	Base coat: rapid-cure aromatic, tan	1	30.0		
	Topcoat: aliphatic, white	1	15.0	45.0	
42	Moisture-curing urethane				
	Base coat: aluminum-pigmented aromatic	1	25.0		
	Topcoat: aluminum-pigmented aliphatic	1	10.0	35.0	
43	Acrylic emulsion, white		2		28.0
44	Catalyzed urethane				
	Base coat: aromatic, light gray	1	19.0		
	Topcoat: aliphatic, white	1	18.0	37.0	3.0
45	Catalyzed rapid-cure urethane				
	Base coat: rapid-cure aromatic, brown	1	50.0		
	Topcoat: aliphatic, white	1	25.0	75.0	3.0
46	Catalyzed urethane				
	Base coat: aromatic, light gray	1	19.0		
	Topcoat: aromatic/aliphatic, white	1	18.0	37.0	3.0
47	Cataylzed rapid-cure urethane				
	Base coat: rapid-cure aromatic, black	1	50.0		
	Topcoat: aromatic/aliphatic, white	1	18.0	68.0	3.0
48	Moisture-curing aromatic urethane, aluminum	2		33.0	3.0

Table 1. Continued

System Number	Coating System Designation and Color	No. of Coats	Dry Film Thickness (mils)	Total (mils)	Foam Density (lb/ft³)
49	Moisture-curing urethane				
	Base coat: aromatic, aluminum	1	16.5		
	Topcoat: aliphatic, white	1	14.0	30.5	3.0
50	Catalyzed Urethane				
	Base coat: fast-cure aromatic, brown	1	25.0	48.0	
	Topcoat: aliphatic, white	1	23.0		
51	Catalyzed silicone				
	Base coat: single component, high modulus, off-white	1	10.0	20.0	
	Topcoat: single component, high modulus, off-white	1	10.0		
52	Catalyzed urethane				
	Base coat: aromatic, gray	2	18.0	38.0	
	Topcoat: aliphatic, white	1	20.0		
53	Catalyzed urethane				
	Base coat: aromatic, gray	2	75.0		
	Topcoat: aliphatic, white	1	15.0	90.0	
54	Moisture-curing urethane				
	Base coat: aromatic, black	2	13.0	18.0	
	Topcoat: aliphatic, white	2	5.0		

Table 2. Permeability Designations

System Type	Vapor Permeability
Silicone	Permeable
Butyl/Hypalon	Impermeable
Hypalon	Impermeable
Acrylic Emulsion	Permeable
Neoprene/Hypalon	Impermeable
Butyl	Impermeable
Aluminum-Pigmented Hydrocarbon Modified	Permeable
Chlorinated Rubber	Permeable
Urethanes	Permeable and impermeable
Aluminum Asphalt	Impermeable
Urethane/Hypalon	Impermeable
Urethane/Silicone	Impermeable
Neoprene Asphalt/Acrylic	Permeable
Rigid Cementitious	Permeable

Table 3. Degradation of Uncoated PUF

Foam Density lb/ft³	Degradation of Uncoated PUF (in.) (years exposed)						Degradation per year (in.)
(a) Seashore Exposure							
2.0	0.168(1.2)[a]	0.291(1.7)	0.460(3.1)	0.587(4.0)	0.763(5.8)	1.128(8.1)	0.139[b]
2.5	0.127(1.2)	0.240(2.2)	0.332(3.1)	0.443(3.7)	0.551(5.8)	0.696(8.1)	0.085
3.0	0.102(1.0)	0.200(2.0)	0.320(3.1)	0.412(4.7)	---	0.630(7.0)	0.090
(b) Desert Exposure							
2.0	0.102(1.2)	0.248(2.0)	0.455(3.1)	0.628(4.0)	---	---	0.157
2.5	0.137(1.0)	0.235(2.0)	0.335(3.1)	0.452(4.0)	---	---	0.113
3.0	0.136(0.8)	0.147(2.0)	0.266(2.8)	---	---	---	0.095
(c) Mountain Exposure							
2.0	0.318(1.2)	0.524(2.0)	0.710(3.1)	0.910(4.0)	---	---	0.228
2.5	0.198(1.1)	0.456(2.0)	0.584(3.1)	0.708(4.0)	---	---	0.177
3.0	0.117(0.8)	0.222(2.0)	0.324(3.1)	---	---	---	0.104

[a]Average of at least three samples.

[b]Obtained by dividing the total degradation by the latest time in years.

Table 4. Adhesion Properties of Coatings

Coating System and Description	Before Exposure		0.25 Years Exposure		0.75 Years Exposure		1-1/2 Years Exposure		2-1/2 Years Exposure		3-1/2 Years Exposure		4-1/2 Years Exposure	
	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode
Silicones														
1 Catalyzed silicone	11.1a	6[b]	9.9	6	10.4	6	7.6	6	4.3	6,3	--	--	9.9	6
1G Catalyzed silicone with granules	--	--	--	--	--	--	--	--	--	--	--	--		
2 Moisture-curing silicone,	9.9	6	9.9	6	10.7	6	8.9	6	8.6	6	--	--	9.8	6
2A Moisture-curing silicone	10.0	6,1	9.2	3,6	10.2	6	9.9	3,6	9.1	6	--	--	11.9	6
2G Moisture-curing silicone with granules	--	--	27.2	4	14.7	7	20.9	7	19.1	7	45.4	7	9.6	7
Butyl-Hypalons														
3 Catalyzed butyl-hypalon	7.7	5,3	7.6	3	6.5	5,2	5.2	3	5.1	3	--	--	7.2	2
4 Catalyzed butyl-hypalon	13.0	5,3	12.0	5	12.2	5	10.0	5	10.5	5	--	--	12.6	5
9 Catalyzed butyl-hypalon	16.0	5,6,2	16.1	5,6,2	17.1	6	14.8	6,3	14.0	6	--	--	15.7	6
Hypalons														
5 Hypalon mastic	20.5	6	18.2	6	18.3	6	15.8	6	12.5	6,1	--	--	13.7	6
12 Hypalon mastic	--	--	--	--	--	--	--	--	13.4	6	--	--	13.7	6
12A Hypalon mastic	21.4	6	17.2	6	18.9	6	15.7	6	14.7	6	--	--	17.7	6
Acrylics														
6 Acrylic emulsion	13.8	5	14.6	5	17.3	5,6	14.6	4	--	--	20.3	6,4		
6A Acrylic emulsion	17.1	6	16.4	6	17.7	6	16.4	6	14.6	4	--	--	17.8	6
20 Acrylic emulsion	--	--	19.0	6	20.1	6	17.5	6	20.7	6	18.1	6	15.9	6
31 Acrylic emulsion	18.3	6	16.9	6	29.4	6	19.6	6	11.4	4	16.8	4	14.9	4,6
43 Acrylic emulsion	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6G Acrylic emulsion with granules	--	--	24.8	7	26.1	7	21.5	7	21.5	6	33.1	6,7	19.6	6
24G Acrylic emulsion with granules	--	--	24.3	4	18.8	6	24.2	6	17.5	6	19.8	6	19.4	6
35GC Acrylic emulsion with granules	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 4. Continued

Coating System and Description	Before Exposure		0.25 Years Exposure		0.75 Years Exposure		1-1/2 Years Exposure		2-1/2 Years Exposure		3-1/2 Years Exposure		4-1/2 Years Exposure	
	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode
36GC Acrylic emulsion with granules	--	--	--	--	--	--	--	--	--	--	--	--	--	--
32 Acrylic emulsion	14.5	6	--	--	--	--	13.4	6	20.4	6	16.4	6	11.1	6
21 Acrylic emulsion	12.5	4,3	--	--	17.4	4	23.9	4	13.3	4	14.6	4	33.6	6,4
Neoprene-Hypalon														
7 Neoprene-hypalon	22.0	6	20.1	6	22.6	6	16.4	6	18.5	6	--	--	17.8	6
Butyl														
8 Aluminum-pigmented butyl	10.9	5	10.6	5	13.1	5	10.7	5	10.4	5	--	--	11.1	35
Chlorinated Rubber														
11 Chlorinated rubber	18.4	6	15.3	6	17.9	6	14.1	6	16.1	6	17.8	6	17.8	6
15 Fibrated aluminum asphalt	16.8	3	14.5	4,5	10.2	4	6.4	4	7.6	4	--	--	8.3	4
Urethanes														
10 Catalyzed aluminum-pigmented	15.4	6	14.0	6	16.7	6	13.2	6	15.4	6	--	--	13.0	6
10A Catalyzed aluminum-pigmented	13.0	--	15.9	6	14.7	6	19.4	6	14.5	6	11.6	6	6.1	6
17 Catalyzed aluminum-pigmented	--	--	7.5	2	11.4	2	13.2	2	14.2	2	12.5	2	12.2	2
13 Catalyzed aliphatic over aromatic	19.5	1,5	16.5	6,2	18.5	6	15.3	6,2	14.8	6,2	--	--	13.0	6
13AC Catalyzed aliphatic over aromatic	16.3	6	19.2	6	18.1	6	15.5	6	19.5	6	19.6	6	17.8	6
38 Catalyzed aliphatic over aromatic	--	--	--	--	--	--	--	--	--	--	--	--	--	--
44 Catalyzed aliphatic over aromatic	--	--	--	--	--	--	--	--	--	--	--	--	--	--
25 Catalyzed aliphatic over aromatic	--	--	14.5	6	16.2	6,4	20.1	2	17.3	6	16.5	4	14.5	4
18 Catalyzed aromatic	--	--	17.1	6	18.1	6	17.5	6	18.6	6	17.5	6	17.8	6
37 Catalyzed aromatic	--	--	--	--	--	--	--	--	--	--	--	--	--	--
46 Catalyzed aromatic/aliphatic over aromatic	--	--	--	--	--	--	--	--	--	--	--	--	--	--
26G Catalyzed aromatic with granules	--	--	6.0	2	21.7	2	20.6	2	14.3	2,6	26.0	2	9.2	4

Table 4. Continued

Coating System and Description	Before Exposure		0.25 Years Exposure		0.75 Years Exposure		1-1/2 Years Exposure		2-1/2 Years Exposure		3-1/2 Years Exposure		4-1/2 Years Exposure	
	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode
14 Moisture-curing aromatic	--	--	--	--	--	--	--	--	5.5	4	--	--	11.5	4
14A Moisture-curing aromatic	22.4	6	12.9	6,1	11.0	4,6	8.2	4	6.3	4	8.7	4	8.7	4
48 Moisture-curing aromatic	--	--	--	--	--	--	--	--	--	--	--	--	--	--
22G Moisture-curing aromatic	--	--	19.2	7	10.4	7	14.4	2	10.7	7	22.3	7	11.9	7
34 Moisture-curing aromatic	19.4	3	22.6	3	19.6	6	29.8	3	23.8	6	--	--	28.3	6
27G Moisture-curing aluminum-pigmented urethane	--	--	15.8	4	15.6	4	14.6	4	14.8	4,6	16.0	4	15.6	4,6
28G Moisture-curing aromatic with granules	--	--	21.6	7	22.5	7	13.2	7	16.3	7	18.4	7	31.1	7
33 Moisture-curing aliphatic over aromatic	14.8	3	24.8	3	26.5	6	38.9	2	28.3	2	28.3	2,6	24.0	6
49 Moisture-curing aliphatic over aromatic	--	--	--	--	--	--	--	--	--	--	--	--	--	--
42 Moisture-curing aliphatic over aluminum-pigmented aromatic	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Urethane-Hypalons														
16C Catalyzed urethane-hypalon	--	--	--	--	--	--	--	--	--	--	--	--	--	--
16AC Catalyzed urethane-hypalon	15.6	6	15.7	6,2	17.3	6	--	--	16.5	6	16.3	6	12.0	6
Urethane-Silicone														
19 Moisture-curing silicone over catalyzed urethane	--	--	5.0	2	4.3	2	3.1	2	4.0	2	0.2	2	4.4	2
23 Moisture-curing silicone over moisture-curing urethane	--	--	5.4	2	5.9	2	5.4	2	6.2	2	0.2	2	6.4	2
30 Acrylic emulsion over neoprene asphalt	8.6	3	10.8	2	7.3	6	8.6	5	8.7	2	10.8	2,6	6.0	2

Table 4. Continued

Coating System and Description	Before Exposure		0.25 Years Exposure		0.75 Years Exposure		1-1/2 Years Exposure		2-1/2 Years Exposure		3-1/2 Years Exposure		4-1/2 Years Exposure	
	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode
Rapid-Cure Urethane														
40 Catalyzed aliphatic over rapid-cure aromatic	--	--	--	--	--	--	--	--	--	--	--	--	--	--
41 Catalyzed aliphatic over rapid-cure aromatic	--	--	--	--	--	--	--	--	--	--	--	--	--	--
45 Catalyzed aliphatic over rapid-cure aromatic	--	--	--	--	--	--	--	--	--	--	--	--	--	--
47 Catalyzed aromatic/ aliphatic over rapid-cure aromatic	--	--	--	--	--	--	--	--	--	--	--	--	--	--
39 Rigid cementitions	--	--	--	--	--	--	--	--	--	--	--	--	--	--

[a]Crosshead speed was 0.5 cm/minute.

[b]1. Adhesive failure of probe to coating.
2. Adhesive failure between topcoat and base coat.
3. Adhesive failure of coating to foam surface.
4. Cohesive failure in topcoat.
5. Cohesive failure in base coat.
6. Cohesive failure in foam.
7. Adhesive failure of granules to coating.

Table 5. Adhesion Properties of Coatings on PUF Panels Aged Prior to Coating

Foam Age Before Coating	2 Months Exposure		9 Months Exposure		1-1/2 Years Exposure		2-1/2 Years Exposure		3-1/2 Years Exposure		4-1/2 Years Exposure	
	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode	Stress kg/cm^2	Failure Mode
System 2: Moisture-Curing Silicone												
1 hour	8.5[a]	3,6[b]	7.1	3	8.4	3	7.3	3,6	11.2	3,6	10.5	3,6
3 hours	8.7	3,6	8.7	3,6	6.0	3	9.8	3,6	11.5	3,6	10.1	3,6
24 hours	7.6	3	7.2	3	5.6	3	7.4	3	8.5	3,6	8.9	3,6
48 hours	6.5	3	7.0	3	5.4	3	5.5	3	7.4	3,6	5.3	3
72 hours	5.5	3	4.9	3	4.9	3	4.3	3	4.4	3	4.2	3
9 days	5.9	3	5.7	3	5.6	3	4.3	3	5.3	3	5.2	3
System 7: Neoprene-Hypalon												
1 hour	22.9	6,4	18.8	6,2	15.4	2,6	17.8	6	21.1	6	20.6	6
3 hours	20.1	6,2,4	17.7	6,2	14.9	6	16.1	6	15.5	6	19.2	6
24 hours	21.6	6,2	18.2	6,2	15.0	6	15.4	6	19.5	6	21.2	6
48 hours	20.7	6	18.8	6	15.2	6	17.0	6	19.2	6	16.1	6
72 hours	22.9	6	18.6	6	16.9	6	17.1	6	18.1	6,2	21.0	6
9 days	18.9	6	16.9	6	15.7	6	14.3	6	17.7	6,3	11.6	6,3

[a]Crosshead speed was 0.5 cm/minute.

[b]For definition of failure code, see Footnote b, Table 4.

Table 6. Results of Wind-Driven Rain Tests on Coated Specimens

Coating System and Description	Vapor Permeability Of Coating	Weight Gain in Grams						
		Before Exposure	0.25 Years Exposure	0.75 Years Exposure	1-1/2 Years Exposure	2-1/2 Years Exposure	3-1/2 Years Exposure	4-1/2 Years Exposure
Silicones								
1 Catalyzed silicone	Yes	1.0[a]	0.4[b]	0.2[b]	0.5[b]	0.7[b]	--	0.9[b]
1G Catalyzed silicone with granules	Yes	0.5	0.4	0.2	0.5	1.3	--	5.4
2 Moisture-curing silicone	Yes	0.5	0.4	0.2	0.6	1.0	--	0.0
2A Moisture-curing silicone	Yes	0.6	0.3	0.2	0.5	0.3	--	1.1
2G Moisture-curing silicone with granules	Yes	--	1.5	0.0	4.6	4.4	7.0[b]	1.3
29 Silicone emulsion	Yes	0.1	1.2	--	--	1.3	--	1.1
Butyl-Hypalons								
3 Catalyzed butyl-hypalon	No	0.4	0.5	0.9	1.5	1.4	--	4.1
4 Catalyzed butyl-hypalon	No	0.5	0.2	0.2	1.0	0.5	--	1.1
9 Catalyzed butyl-hypalon	No	0.7	1.0	1.7	1.0	0.3	--	-0.7[c]
Hypalons								
5 Hypalon mastic	No	0.5	0.2	2.2	1.2	1.0	--	1.9
12 Hypalon mastic	No	--	--	--	18.0	--	--	3.4
12A Hypalon mastic	No	0.8	0.7	1.6	2.4	2.0	--	1.7
Acrylics								
6 Acrylic emulsion	Yes	0.2	0.6	1.4	0.6	1.6	--	0.9
6A Acrylic emulsion	Yes	3.4	0.2	2.4	1.0	1.4	--	1.4
20 Acrylic emulsion	Yes	--	1.7	0.5	3.3	2.0	1.4	2.7
31 Acrylic emulsion	Yes	6.3	1.6	2.2	3.3	1.4	--	2.0
43 Acrylic emulsion	Yes	--	--	--	--	--	--	--
6G Acrylic emulsion with granules	Yes	--	1.5	5.7	6.1	5.7	7.4	30.5
24G Acrylic emulsion with granules	Yes	--	0.2	0.1	--	12.8	19.0	4.5
35GC Acrylic emulsion with granules	Yes	--	--	--	--	--	--	--
36GC Acrylic emulsion with granules	Yes	3.8	1.6	7.1	1.2	1.4	--	--
32 Acrylic emulsion	Yes	1.2	--	--	0.9	3.9	--	7.7
21 Acrylic emulsion	Yes	--	18.8	--	2.1	2.5	3.5	6.5
7 Neoprene-hypalon	Moderate	0.8	0.7	1.8	0.8	0.5	--	1.4
8 Aluminum-pigmented butyl	No	0.4	0.5	2.0	0.3	0.6	--	0.9
11 Chlorinated rubber	Moderate	0.7	0.7	0.4	0.5	0.6	--	0.6
15 Fibrated aluminum asphalt	No	1.9	0.4	0.2	1.4	0.7	--	--

Table 6. Continued

Coating System and Description	Vapor Permeability Of Coating	Weight Gain in Grams						
		Before Exposure	0.25 Years Exposure	0.75 Years Exposure	1-1/2 Years Exposure	2-1/2 Years Exposure	3-1/2 Years Exposure	4-1/2 Years Exposure
Acrylics (Continued)								
10 Catalyzed aluminum-pigmented	Moderate	2.1	1.6	1.9	0.9	1.9	--	9.7
10A Catalyzed aluminum-pigmented	Moderate	0.8	0.3	0.5	0.2	3.0	19.3	34.5
17 Catalyzed aluminum-pigmented	Moderate	--	1.1	1.2	2.4	0.9	2.1	0.0
13 Catalyzed aliphatic over aromatic	Yes	0.8	0.4	0.6	0.5	0.5	--	1.3
13AC Catalyzed aliphatic over aromatic	Yes	0.7	0.3	0.6	1.7	2.6	0.2	1.7
38 Catalyzed aliphatic over aromatic	Yes	0.3	1.7	2.2	17.1	0.9	--	--
44 Catalyzed aliphatic over aromatic	Yes	--	--	--	--	--	--	--
25 Catalyzed aliphatic over aromatic	Yes	--	0.0	6.3	0.9	0.9	3.8	4.8
18 Catalyzed aromatic	Yes	--	0.8	0.4	1.5	1.0	2.6	2.7
37 Catalyzed aromatic	Yes	0.3	1.9	0.0	4.4	1.0	--	--
46 Catalyzed aromatic/aliphatic over aromatic	Yes	--	--	--	--	--	--	--
26G Catalyzed aromatic with granules	Yes	--	2.4	2.8	3.1	3.2	8.3	6.5
14A Moisture-curing aromatic	Yes	0.4	1.7	2.8	3.9	3.4	6.4	--
48 Moisture-curing aromatic	Yes	--	--	--	--	--	--	--
22G Moisture-curing aromatic	Yes	--	3.1	4.4	4.6	0.5	8.0	16.8
34 Moisture-curing aromatic	Yes	0.7	2.7	2.1	2.3	--	--	--
27G Moisture-curing aluminum-pigmented urethane	Moderate	--	2.0	0.0	1.0	0.1	1.5	3.5
28G Moisture-curing aromatic with granules	Yes	--	1.4	2.8	1.1	5.0	3.0	--
33 Moisture-curing aliphatic over aromatic	Yes	0.3	3.6	2.4	2.9	--	--	--
49 Moisture-curing aliphatic over aromatic	Yes	--	--	--	--	--	--	--

Table 6. Continued

Coating System and Description	Vapor Permeability Of Coating	Weight Gain in Grams						
		Before Exposure	0.25 Years Exposure	0.75 Years Exposure	1-1/2 Years Exposure	2-1/2 Years Exposure	3-1/2 Years Exposure	4-1/2 Years Exposure
Urethane-Hypalons								
16C Catalyzed urethane-hypalon	No	0.5	0.4	0.5	0.8	1.1	0.6	3.3
16AC Catalyzed urethane-hypalon	No	0.2	0.8	0.8	0.2	2.4	1.1	0.9
Urethane-Silicone								
19 Moisture-curing silicone over catalyzed urethane	Yes	--	0.5	0.7	0.5	1.9	0.5	0.4
23 Moisture-curing silicone over moisture-curing urethane	Yes	--	2.1	-1.4	-0.6	-1.4	10.9	9.1
30 Acrylic emulsion over neoprene asphalt	Moderate	1.9	1.1	0.4	0.5	1.0	--	2.5
Rapid-Cure Urethane								
40 Catalyzed aliphatic over rapid-cure aromatic	Yes	--	--	--	--	--	--	--
41 Catalyzed aliphatic over rapid-cure aromatic	Yes	--	--	--	--	--	--	--
45 Catalyzed aliphatic over rapid-cure aromatic	Yes	--	--	--	--	--	--	--
47 Catalyzed aromatic/aliphatic over rapid-cure aromatic	Yes	--	--	--	--	--	--	--

[a]Exposed to wind-driven rain test for 7 hours.

[b]Exposed to wind-driven rain test for 24 hours.

[c]Negative weights mean the specimen lost weight.

Table 7. Results of Impact Tests

Coating and System Number	Foam Density (pcf)	Weight at Breaking Limit, grams						
		Before Exposure	0.25 Years Exposure	0.75 Years Exposure	0.5 Years Exposure	2.5 Years Exposure	3.5 Years Exposure	4.5 Years Exposure
Silicones								
1	2.0	300	--	300	300	--	--	250
1G	2.0	300	--	300	300	--	--	300
2	2.0	500	--	500	500	--	--	384
2A	2.5	500	--	500	500	--	--	300
2G	3.0	--	00	600	600	00	--	650
29	3.0	500	84	400	--	00	--	400
Butyl-Hypalons								
3	2.0	300	--	160	160	--	--	250
4	2.0	300	--	160	160	--	--	250
9	2.0	160	--	160	160	--	--	150
Hypalon								
5	2.0	500	--	300	500	--	--	250
12	2.0	300	--	160	160	--	--	250
12A	2.0	500	--	300	500	--	--	384
Acrylic								
6	2.0	500	--	500	500	--	--	300
6A	2.0	500	--	500	500	400	--	400
20	3.0	--	--	129	129	125	400	450
31	3.0	475	--	250	129	380	400	400
43	3.0	900	--	--	--	--	--	--
6G	3.0	--	00	400	500	400	400	450
24G	3.0	--	--	200	129	129	400	400
35GC	--	--	--	--	--	--	--	--
36GC	2.5	750	650	575	900	600	--	--
32	2.0	500	50	650	500	550	--	600
21	2.5	--	--	--	129	129	129	381

Table 7. Continued

Coating and System Number	Foam Density (pcf)	Weight at Breaking Limit, grams						
		Before Exposure	0.25 Years Exposure	0.75 Years Exposure	0.5 Years Exposure	2.5 Years Exposure	3.5 Years Exposure	4.5 Years Exposure
Neoprene-Hypalon								
7	2.0	160	--	160	300	--	--	500
Butyl								
8	2.0	500	--	500	400	--	--	250
Chlorinated Rubber								
11	2.0	300	--	160	160	--	--	260
Fibrated Aluminum Asphalt								
15	2.5	160	--	160	160	--	--	129
Urethanes								
10	2.0	500	--	160	160	--	--	400
10A	2.5	160	--	--	300	200	129	400
17	3.0	--	700	525	900	600	700	800
13C	2.0	500	--	--	500	--	--	400
13AC	2.5	550	--	--	200	250	275	400
38	3.0	800	850	675	800	600	600	650
44	3.0	952[a]	--	--	--	--	--	--
25	2.0	--	--	--	850	930[a]	850	800
18	3.0	--	950	956[a]	958[a]	930[a]	800	700
37		450	400	380	500	450	--	--
46	3.0	--	--	--	--	--	--	--
26G	2.0	--	--	958	500	750	600	900[a]
14	2.0	500	--	500	500	--	--	400
14A	2.5	500	--	500	500	--	475	--
48	3.0	--	--	--	--	--	--	--
22G	3.0	--	--	956[a]	958[a]	930[a]	950[a]	950[a]
34		958[a]	954[a]	950[a]	925[a]	--	--	--
27G		--	--	400	--	400	425	--
28G		--	--	956[a]	--	950[a]	925[a]	--

Table 7. Continued

Coating and System Number	Foam Density (pcf)	Weight at Breaking Limit, grams						
		Before Exposure	0.25 Years Exposure	0.75 Years Exposure	0.5 Years Exposure	2.5 Years Exposure	3.5 Years Exposure	4.5 Years Exposurer
Urethanes (Cont.)								
33		600	350	125	725	--	--	--
49	3.0	--	--	--	--	--	--	--
42		952[a]	952[a]	925[a]	--	--	--	--
Urethane-Hypalone								
16C	2.0	700	--	--	550	300	500	700
16AC	3.0	480	--	--	375	550	375	400
Urethane-Silicone								
19	3.0	--	--	961[a]	--	--	950[a]	700
23	3.0	--	--	964[a]	900	950[a]	950[a]	900[a]
Neoprene-Asphalt/Acrylic Emulsion								
30	3.0	961[a]	958[b]	956[b]	930b	400	--	400
Rapid-Cure Urethane								
40	2.0	--	952	--	--	--	--	--
41		--	--	--	--	--	--	--
45	3.0	--	--	--	--	--	--	--
47	3.0	--	--	--	--	--	--	--
Rigid Cementitious								
39		--	--	--	--	--	--	--

[a]Maximum weight available.

[b]Topcoat broken at 450 gm.

Table 8. Tensile Test Results of Free Films of Coating Systemsn For PUF[a]

System Number and Description	Cure Time[b]					
	3 Months		6 Months		12 Months	
	Maximum Tensile Strength (gm/mm^2)	Elongation (%)	Maximum Tensile Strength (gm/mm^2)	Elongation (%)	Maximum Tensile Strength (gm/mm^2)	Elongation (%)
Silicones						
1	241	121	218	97	269	91
2	--	--	251	201	292	256
2	284	230	307	236	--	--
29	285	883	--	--	322	636
Butyl-Hypalons						
3	--	--	124	308	139	235
4	--	--	48	104	87	108
4	82	72	110	54	--	--
9	--	--	108	183	164	128
Hypalons						
5	--	--	87	489	--	--
12	--	--	172	329	203	292
12A	24	171	31	174	--	--
Acrylics						
6	--	--	55	218	101	190
6A	--	--	74	122	112	104
6G	--	--	--	--	86	310
20	46	3,000+	--	--	57	2,835+
31	194	106	--	--	189	73
36GC	31	337	--	--	34	423
36GC	35	196	--	--	26	506

Table 8. Continued

System Number and Description	Cure Time[b]					
	3 Months		6 Months		12 Months	
	Maximum Tensile Strength (gm/mm^2)	Elongation (%)	Maximum Tensile Strength (gm/mm^2)	Elongation (%)	Maximum Tensile Strength (gm/mm^2)	Elongation (%)
Neoprene-Hypalon						
7	--	--	324	315	387	251
Butyl						
8	--	--	86	123	60	91
8	34	84	41	70	--	--
Chlorinated Rubber						
11	173	118	178	88	190	104
Fibrated Aluminum Asphalt						
15	39	57	72	34	-	--
15	53	147	--	--	75	68
Urethanes						
10	175	738	226	776	165	725
17	--	--	--	--	38	1,425
13	1,054	698	1,115	660	2,040	779
13	437	531	--	--	--	--
38	--	--	315	173	334	372
25	244	1,182	--	--	238	1,093
18	--	--	--	--	389	961
37	--	--	414	91	349	96
14	173	432	174	358	--	--
22G	--	--	--	--	114	1,051
34	--	--	230	285	328	526
33	--	--	444	242	316	458

Table 8. Continued

System Number and Description	Cure Time[b]					
	3 Months		6 Months		12 Months	
	Maximum Tensile Strength (gm/mm^2)	Elongation %	Maximum Tensile Strength (gm/mm^2)	Elongation %	Maximum Tensile Strength (gm/mm^2)	Elongation %
Urethane-Hypalon						
16	1,019	894	--	--	--	--
16	--	--	1,366	903	--	--
Urethane-Silicone						
19	--	--	--	--	177	721

[a]Speed of Testing was 0.5 cm per minute.

[b]Length of time that free coating films cured under laboratory conditions before testing.

Table 9. Example Coating Deterioration Data Sheets

Coating Deterioration Factors

Months Exposed	Overall Performance	Adhesion	Blistering	Chalking	Checking	Cohesion	Cracking	Flaking/ Spalling	Peeling	Pinholes	Nail Damage	Erosion	No. of Breaks in Coating	No. of Bird Pecks	Reading Date	Remarks
a. System 1, Seashore Site																
16	10	10	10	10	10	10	10	10	10	10	10	10	0	0	1-30-76	In excellent condition.
48	10	10	10	10	10	10	10	10	10	10	10	10	0	0	10-06-78	In excellent condition.
68	10	10	10	10	10	10	10	10	10	10	10	10	2'	2	6-18-80	Retains dirt; looks very good. 1. Mechanical Breaks.
80	10	10	10	10	10	10	10	10	10	10	10	10	2'	3	6-22-81	One new bird peck. 1. Mechanical Breaks.
104	10	10	10	10	10	10	9'+	10	10	10²	10	10	2	3	6-29-83	1. Small Cracks on lower right. 2. A few pinholes.
b. System 8, Seashore Site																
14	10-	10	10	10	10-	10	10	10	10	7	10	10	0	0	5-30-75	In excellent condition.
55	7	10	10	4	0	10	8	10	10	7	10	10	0	0	10-06-78	Deteriorating rapidly.
75	6	10	10	4	4	10	8	10-	10	6	10	10	0	2	6-18-80	Failed; checking developing into cracking; needs repair.
87	4	10	10	0	4	10	4	10-	10	4	10	10	Many	2	6-22-81	Failed.
101	4	10	10	0	4	10	4	10-	10	4	10	10	Many	2	8-09-82	Failed.

Table 10. Latest Overall Performance Ratings For All Coating Systems

Coating System and Description	System Number	Seashore		Desert		Mountain	
		Rating	Time (yr/mo)	Rating	Time (yr/mo)	Rating	Time (yr/mo)
Silicones							
Catalyzed: Cement gray over medium gray	1	10[a]	11-1	10-	3-0	9	7-11
Catalyzed: Cement gray over medium gray with granules	1G	1-	11-1	9	11-4	10-	7-11
Catalyzed: Off-White	51	10	03	--	--	--	--
Moisture-Curing: White over light gray	2[b]	9	11-8	9+	5-1	9+	5-1
Moisture-Curing: White over light gray with granules	2A[c]	10-	10-11	9+	7-6	9	7-6
	2G	10	7-11	10	7-11	10	4-6
Emulsion: Cement gray over medium gray	29	9-	7-1	9+	7-2	10	3-9
Butyl-Hypalons							
Catalyzed: White hypalon over black plural-component butyl	3	7	3-11	2	3-5	2	3-9
Catalyzed: White single-component hypalon over tan butyl	4	10	11-8	9	11-4	8+	7-11
	4A	7	10-11	7	10-11	6	4-8
Catalyzed: White single-component hypalon over black butyl	9	8	11-8	3	11-4	7	5-1
Hypalons							
White single-component hypalon	5	8	11-1	5	11-4	8-	7-11
White hypalon mastic	12	9-	11-1	7	11-4	8+	7-11
	12A	9+	10-11	9-	10-11	8+	7-5
Acrylics							
White emulsion	6	9	11-8	9	11-4	10-	7-11
	6A	9	11-8	9+	5-1	8	5-1
	20	9+	7-11	10-	7-11	9-	4-6
	31	10-	7-1	10	7-2	10	3-9
	43	10	1-11	--	--	--	--
White emulsion with white granules	6G	10	7-11	10	7-11	10	4-6
	24G[d]	10	7-11	10	7-11	10	4-6
White emulsion with gray granules	35GC	10	5-6	--	--	--	--
	36GC	10	5-6	10	5-6	10	1-11
Green emulsion	32	9	7-1	9	7-2	10-	3-9
White cement-filled emulsion (nonelastomeric)	21	9-	7-11	10-	7-9	8	3-11
Neoprene-Hypalon							
White single-component hypalon over black single-component neoprene	7	9	11-8	9	11-4	9	7-11
Butyls							
Catalyzed aluminum-gray, aluminum-pigmented butyl	8	3	11-8	5	11-4	8	7-11
	8A	9-	10-11	9	10-11	8+	7-6

Table 10. Continued

Coating System and Description	System Number	Seashore Rating	Seashore Time (yr/mo)	Desert Rating	Desert Time (yr/mo)	Mountain Rating	Mountain Time (yr/mo)
Chlorinated Rubber							
White over gray	11	10-	11-1	9+	11-4	7	5-1
Fibrated Aluminum-Asphalt							
Aluminum over black	15	10-	10-11	9-	10-11	-6	4-8
Urethanes							
Catalyzed: Aluminum-pigmented	10	7	3-5	8	3-9	6	3-9
	10A	2	9-0	--	--	--	--
	17	9	7-11	9-	7-11	8+	4-8
Catalyzed: White aliphatic over aluminum-gray aromatic	13	10	11-1	9+	11-4	10	7-11
	13C	9-	9-0	9+	9-0	--	--
	13AC	9-	9-0	8-	9-0	9	5-7
Catalyzed: White aliphatic over brown aromatic	38	--	--	9+	5-6	--	--
Catalyzed: White aliphatic over light gray aromatic	44	10-	1-11	--	--	--	--
Catalyzed: White aliphatic over off-white aromatic	25W[e]	9	7-11	9	7-11	10-	4-6
Catalyzed: White aliphatic over gray aromatic	52	10	0-3	--	--	--	--
	53	10	0-3	--	--	--	--
Catalyzed: Gray aliphatic over off-white aromatic	25GY	9	7-11	10	7-11	10	4-6
Catalyzed: Offwhite aromatic over black aromatic	18	9+	7-11	10-	7-11	10	4-6
Catalyzed: White aromatic over aluminum-gray aromatic	37	9+	5-6	9	5-6	9+	1-11
Catalyzed: White aromatic/aliphatic over gray aromatic	46	10-	1-11	--	--	--	--
Catalyzed: Off-white aromatic with green granules	26G	9	7-11	10	7-11	10	4-5
Moisture-curing: Gray aromatic	14	5	3-4	5	3-9	4	3-9
	14A	3	3-2	8-	4-2	5	3-4
Moisture-curing: Aluminum aromatic	48	10	1-11	--	--	--	--
Moisture-curing: tan aromatic with gray granules	22G	8	7-11	10	7-11	10	4-6
Moisture-curing: brown aromatic	34	9	6-3	--	--	--	--
Moisture-curing: aluminum-pigmented aromatic with granules	27G	9-	7-9	10-	7-9	10	3-11
Moisture-curing: aluminum aromatic over aromatic with gray granules	28G	10	7-9	10	7-9	10	3-11
Moisture-curing: White aliphatic over brown aromatic	33	9+	6-3	--	--	--	--
Moisture-curing: White aliphatic over black aromatic	54	10	0-3	--	--	--	--
Moisture-curing: White aliphatic over aluminum aromatic	49	9+	1-11	--	--	--	--
Moisture-curing: Aluminum-pigmented aliphatic over aluminum-pigmented aromatic	42	10	2-3	--	--	--	--
Urethane-Hypalons							
Catalyzed: White single-component hypalon over aluminum-gray urethane	16C	10-	9-0	9-	9-0	9-	5-7
	16AC	9+	9-0	7	9-0	9-	5-7

Table 10. Continued

Coating System and Description	System Number	Seashore		Desert		Mountain	
		Rating	Time (yr/mo)	Rating	Time (yr/mo)	Rating	Time (yr/mo)
<u>Urethane-Silicone</u>							
White moisture-curing silicone over black catalyzed aromatic urethane	19	9+	7-11	9	7-11	9-	4-6
White moisture-curing silicone over tan moisture-curing aromatic urethane	23	10	7-11	9+	7-11	10	4-6
<u>Neoprene Asphalt-Acrylic Emulsion</u>							
White acrylic emulsion over black neoprene asphalt	30	9	7-1	9	7-2	10-	3-9
<u>Rapid-Cure Urethane</u>							
White catalyzed aliphatic over brown rapid-cure aromatic	40	10	2-10	--	--	--	--
	41	10	2-6	--	--	--	--
	45	10-	1-11	--	--	--	--
	50	10	0-3	--	--	--	--
White catalyzed aromatic/aliphatic over black rapid-cure aromatic	47	10-	1-11	--	--	--	--
<u>Rigid Cementitious</u>							
Rigid cementitious over black elastomeric	37	10-	4-6	--	--	--	--

[a]Performance corresponding to numerical ratings
10: Excellent
9+: Very Good
9 to 8: Good
7: Poor
6 to 0: Failed

[b]"A" means that the foam density is different but the coating system is that designated by the digit.

[c]"G" means that granules were applied to the wet topcoat.

[d]"C" means that the panels were sprayed with foam and coated by a private contractor.

[e]"W" means that the topcoat color was white.

[f]"GY" means that the topcoat color was gray.

Table 11. Overall Performance Ratings for Coatings on Foam Aged Prior to Coating

Foam Age Before Coating	System 2: Moisture-Curing Silicone	System 7: Neoprene-Hypalon
1 Hour	10[a,b]	9+
3 Hours	10-	9+
24 Hours	10-	9+
48 Hours	10-	9+
72 Hours	9-	9+
9 Days	9+	9+

[a]For performance equivalents, see Footnote a to Table 10.

[b]All panels were exposed for 10 years and 7 months at the seashore site.

Table 12. Coating Systems With Excellent or Very Good Ratings at All Three Exposure Sites.[a]

Coating System Type	System Number	System Description
Silicones	1G	Catalyzed silicone with granules
	2G	Moisture-curing silicone with granules
Acrylics	6	Acrylic emulsion
	6G	Acrylic emulsion with white granules
	31	Acrylic emulsion
	24G	Acrylic emulsion with white granules
	36GC	Acrylic emulsion with gray granules
Urethanes	13	Catalyzed: aliphatic over aromatic
	18	Catalyzed: aromatic over aromatic
	28G	Moisture-curing: aromatic over aromatic with granules
Urethane-Silicone	23	Moisture-curing silicone over moisture-curing aromatic urethane

[a]After exposure of at least 3 years.

Table 13. Coating Systems With Excellent or Very Good Ratings at Each of the Exposure Sites[a]

Coating System Type	Seashore		Desert System Number		Mountain	
	Excellent	Very Good	Excellent	Very Good	Excellent	Very Good
Silicones	1	--	1	1G	1G	2
	1G	--	2G	2	2G	--
	2A	--	--	2A	29	--
	2G	--	--	29	--	--
Butyl-Hypalons	4	-	--	--	--	--
Hypalons	--	12A	--	--	--	--
Acrylics	31	6	20	6	6	--
	43	20	31	6A	31	--
	6G	--	6G	--	6G	--
	24G	--	24G	--	24G	--
	35GC	--	36GC	--	36GC	--
	36GC	--	21	--	32	--
Neoprene-Hypalon	--	7	--	7	--	--
Chlorinated Rubber	11	--	--	11	--	--
Fibrated Aluminum-Asphalt	15	--	--	--	--	--
Urethanes	13	--	13	--	13	--
	--	--	13C	--	--	--
	--	--	--	38	--	--
	--	--	--	--	--	25W
	--	--	25GY	--	25GY	--
	--	18	18	--	18	--

Table 13. Continued

Coating System Type	Seashore		Desert System Number		Mountain	
	Excellent	Very Good	Excellent	Very Good	Excellent	Very Good
Urethanes (Cont.)						
	--	37	--	--	--	37
	--	--	26G	--	26G	--
	--	--	22G	--	22G	--
	--	--	27G	--	27G	--
	28G	--	28G	--	28G	--
	--	33	--	--	--	--
Urethane-Hypalons	16C	--	--	--	--	--
	--	16AC	--	--	--	--
Urethane-Silicones	--	19	--	--	--	--
	23	--	--	23	23	--
Neoprene Asphalt Acrylic Emulsion	--	--	--	30	--	--
Rigid Cementitious	39	--	--	--	--	--

[a] After exposure of at least 3 years.

Table 14. Effects of Foam Density on Coating Performance

System Number	Foam Density[a]	Performance Ratings		
		Seashore	Desert	Mountain
4	2.0	10	9	8+
4A	2.5	7	7	6
8	2.0	3	5	8
8A	2.5	9-	9	8+
10	2.0	7	8	6
10A	2.5	2	-	-
12	2.0	9-	7	8
12A	2.5	9+	9-	8+
13	2.0	10	9+	10
13AC	3.0	9-	8-	9
14	2.0	5	5	4
14A	2.5	3	8-	5
16A	2.0	10-	9-	9-
16AC	3.0	9+	7	9-
2	2.0	9	9+	9+
2A	2.5	10-	9+	9

[a]Pounds per cubic foot.

Table 15. Ranking of Physical Properties of Coating Systems By System Number and Type

Ranking	Adhesion[a]	Coating Type	Absorption[b]	Coating Type	Impact Strength[c]	Coating Type	Tensile Strength[d]	Coating Type	Elongation[e]	Coating Type
1	21	Acrylic	2	Silicone	13	Urethane	13	Urethane	20	Acrylic
2	28G	Urethane	17	Urethane	26G	Urethane	18	Urethane	17	Urethane
3	34	Urethane	19	Urethane Silicone	23	Urethane Silicone	7	Neoprene-Hypalon	25	Urethane
4	38	Urethane	11	Chlorinated Rubber	17	Urethane	37	Urethane	22G	Urethane
5	6	Acrylic	1	Silicone	25	Urethane	38	Urethane	18	Urethane
6	6G	Acrylic/G	6	Acrylic	18	Urethane	34	Urethane	13	Urethane
7	24G	Acrylic/G	8	Butyl	16C	Urethane-Hypalon	29	Silicone	10	Urethane
8	6A	Acrylic	16AC	Urethane-Hypalon	19	Urethane-Silicone	33	Urethane	19	Urethane-Silicone
9	7	Neoprene-Hypalon	2A	Silicone	2G	Silicone	2	Silicone	29	Silicone
10	11	Chlorinated Rubber	29	Silicone	38	Urethane	1	Silicone	34	Urethane
11	13AC	Urethane	4	Butyl-Hypalon	32	Acrylic	25	Urethane	36GC	Acrylic
12	18	Urethane	2G	Silicone/G	7	Butyl-Hypalon	12	Hypalon	33	Urethane
13	12A	Hypalon	13	Urethane	20	Acrylic	11	Chlorinated Rubber	36GC	Acrylic
14	20	Acrylic	6A	Acrylic	6G	Acrylic	31	Acrylic	38	Urethane
15	9	Butyl-Hypalon	12A	Hypalon	29	Silicone	19	Urethane-Silicone	6G	Acrylic
16	22G	Urethane	13AC	Urethane	6A	Acrylic	10	Urethane	12	Hypalon
17	31	Acrylic	5	Hypalon	31	Acrylic	9	Butyl-Hypalon	2	Silicone
18	25	Urethane	31	Acrylic	24G	Acrylic	3	Butyl-Hypalon	7	Neoprene-Hypalon
19	12	Hypalon	30	Neoprene-Acrylic	10	Urethane	22G	Urethane	3	Butyl-Hypalon
20	10	Urethane	20	Acrylic	10A	Urethane	6A	Acrylic	11	Chlorinated Rubber

[a] In order of highest adhesion strength (kg/cm^2) after 4-1/2 years (Table 4).

[b] In order of lowest weight gain (grams) of water after 4-1/2 years exposure (Table 6).

[c] In order of highest impact strength (grams) after 4-1/2 years exposure (Table 7).

[d] In order of highest tensile strength (gm/cm^2) after 12 months cure time (Table 8).

[e] In order of highest elongation (%) after 12 months cure time (Table 8).

Table 16. Relative Importance of Physical Properties in Coating System Performance[a]

System Number From Table 12	Ranking of Each Physical Property From Table 15				
	Adhesion	Absorption	Impact	Tensile	Elongation
1G	N.I.T.T[b]	N.I.T.T.	N.I.T.T.	Not Tested	Not Tested
2G	N.I.T.T.	12	9	Not Tested	Not Tested
6	5	6	N.I.T.T.	N.I.T.T.	N.I.T.T.
6G	6	N.I.T.T.	14	N.I.T.T.	15
31	17	18	17	14	N.I.T.T.
24G	7	N.I.T.T.	18	Not Tested	Not Tested
36GC	Not Tested	Not Tested	Not Tested	N.I.T.T.	11
13	11	13	N.I.T.T.	1	6
18	12	N.I.T.T.	6	2	5
28G	2	Not Tested	Not Tested	Not Tested	Not Tested
23	N.I.T.T.	N.I.T.T.	3	Not Tested	Not Tested

[a]Correlation between Tables 12 and 15.

[b]Not in top twenty ranking of the given property.

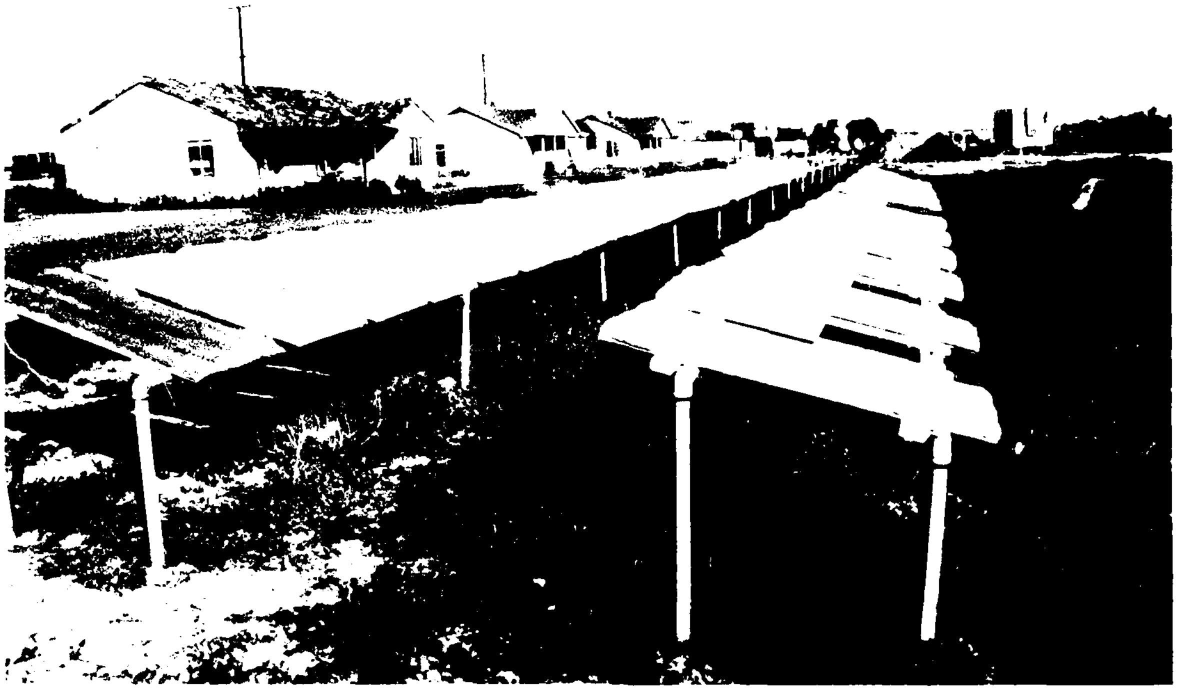


Figure 1. Experimental panels at seashore site, Port Hueneme, California.

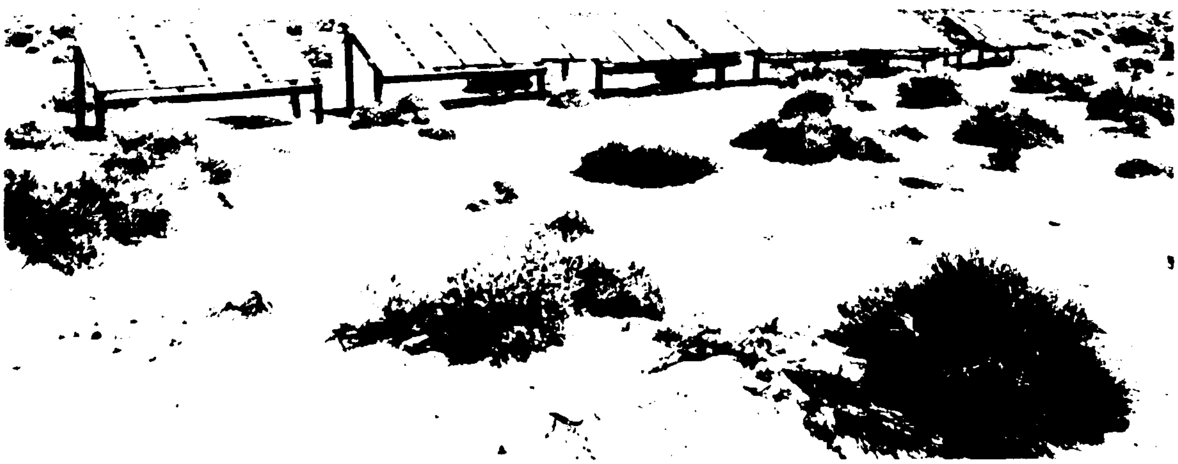
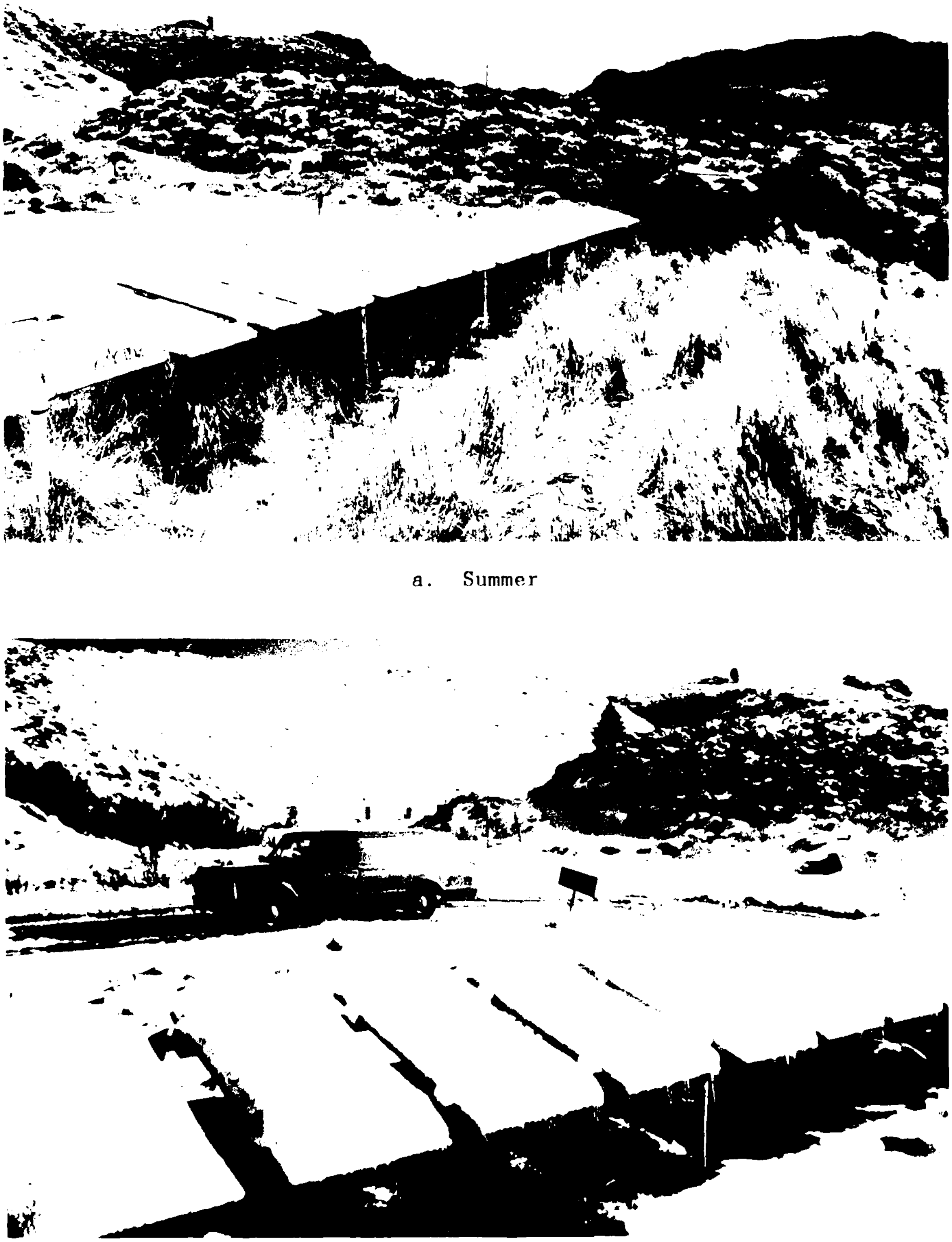


Figure 2. Experimental panels at desert site, NWC, China Lake, California.



a. Summer

b. Winter

Figure 3. Experimental panels at mountain site, MCMWTC, Pickel Meadows, California.

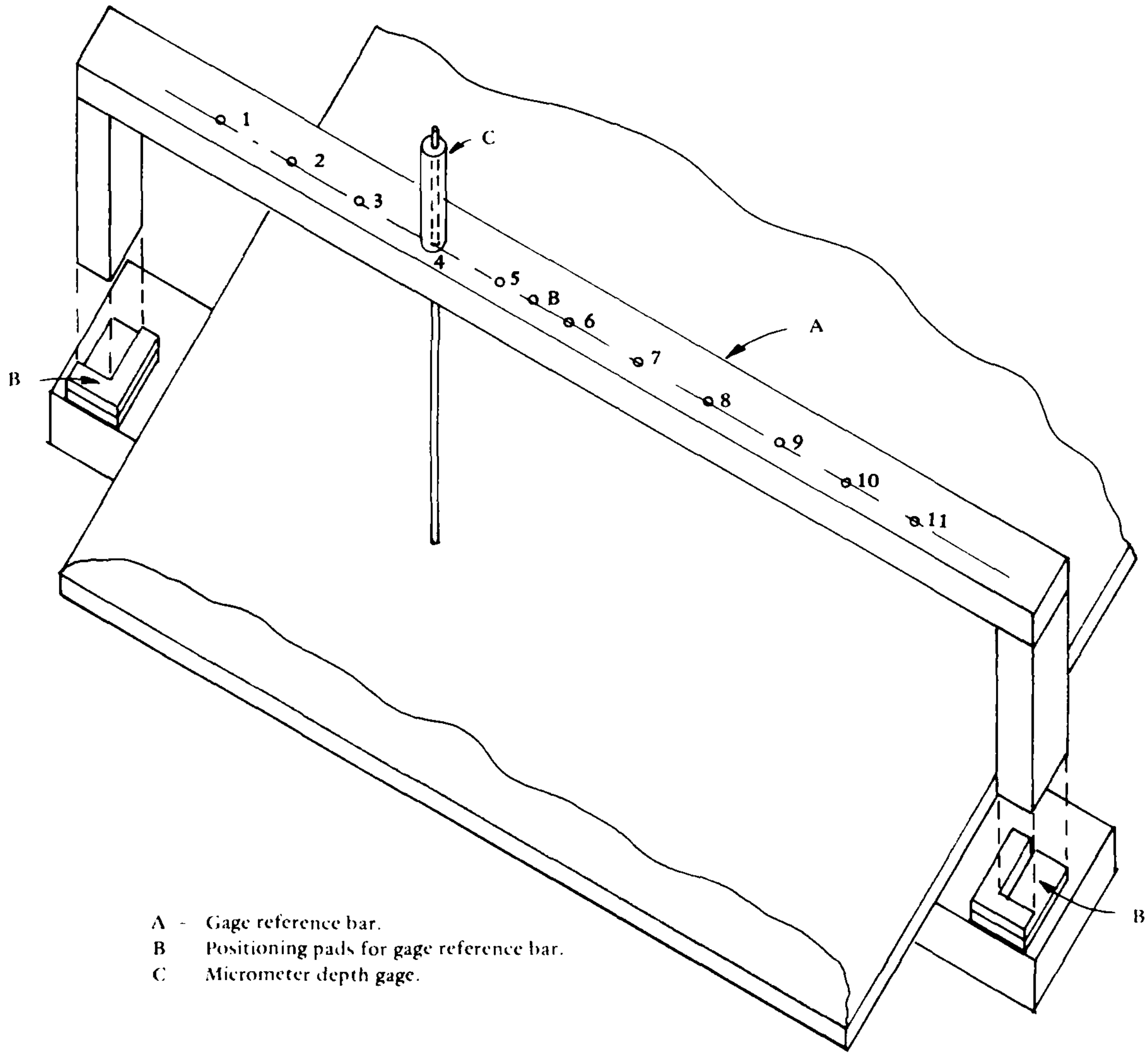


Figure 4. Device for measuring rate of degradation of uncoated urethane foam.

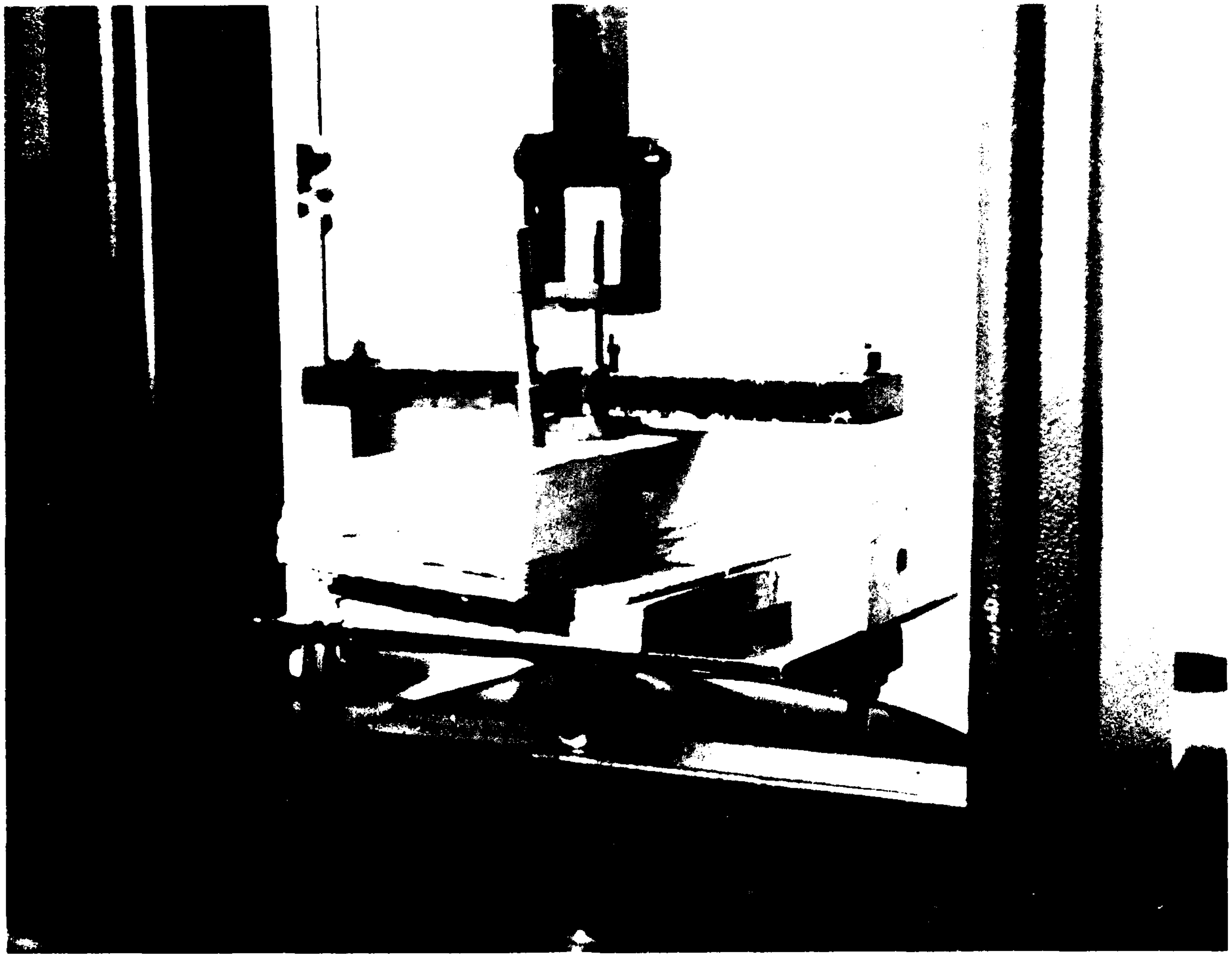


Figure 5. Fixture for determining adhesion properties.

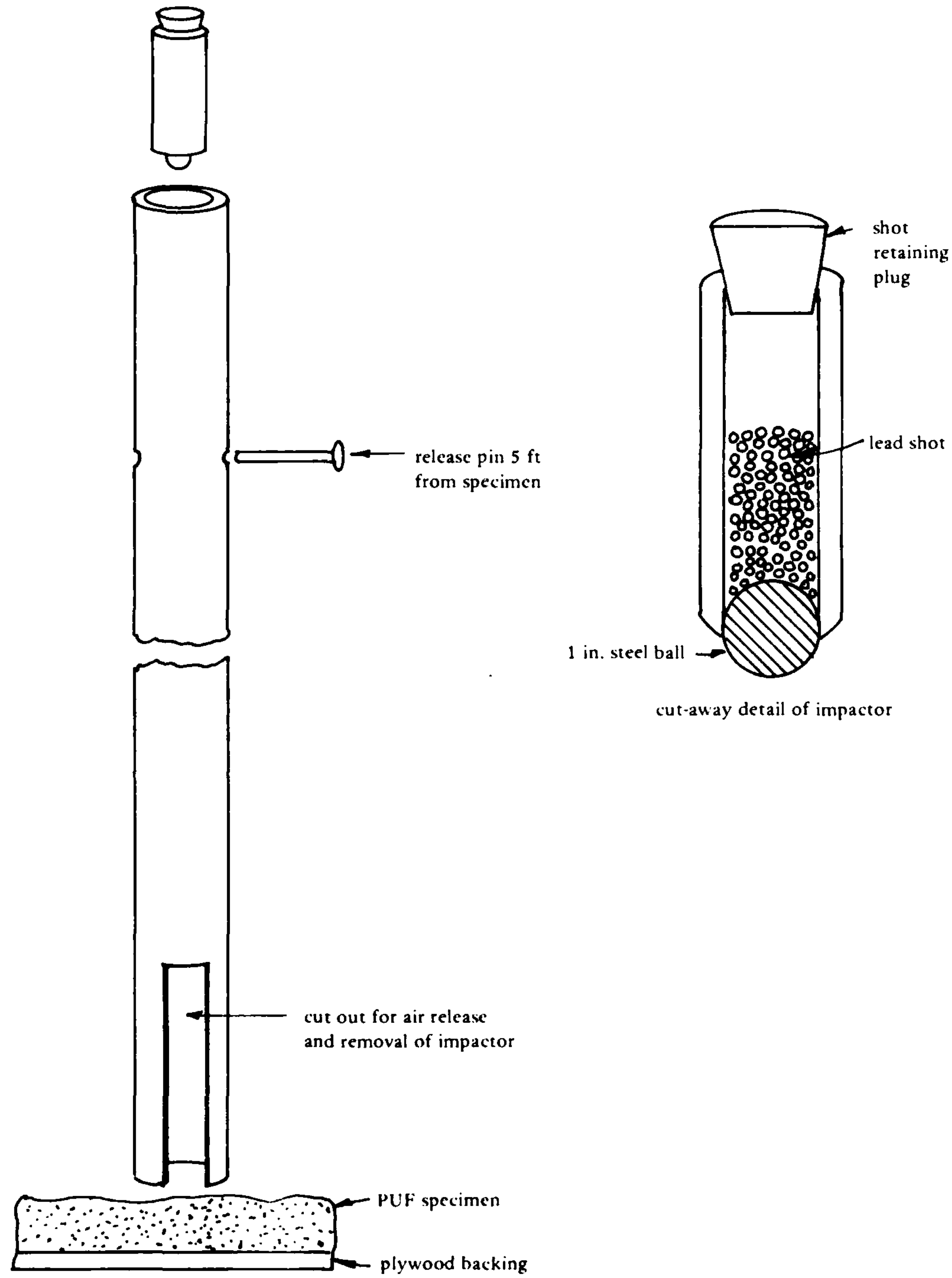
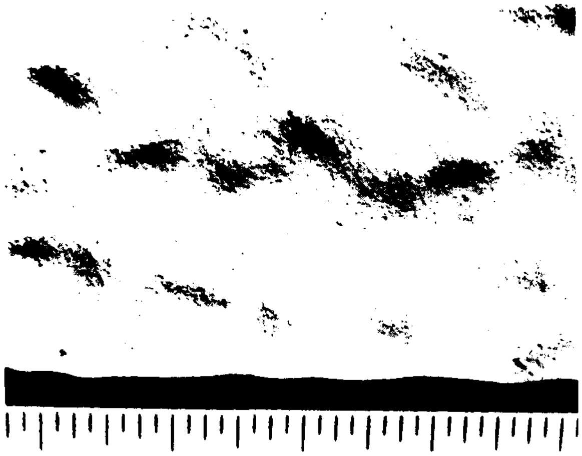
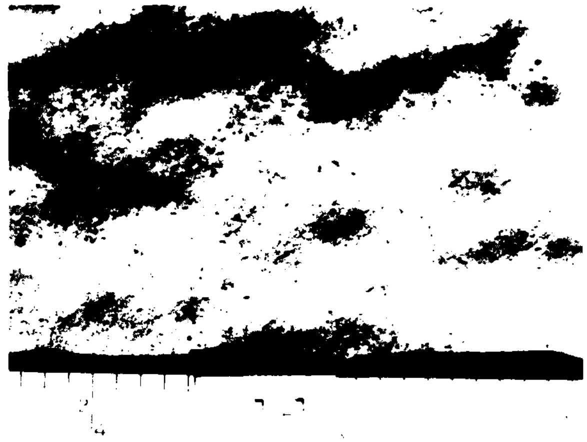


Figure 6. Impact tester and weighted impactor.



a. Before exposure.



b. After 1 year and 4 months.

c. After 3 years and 3 months.

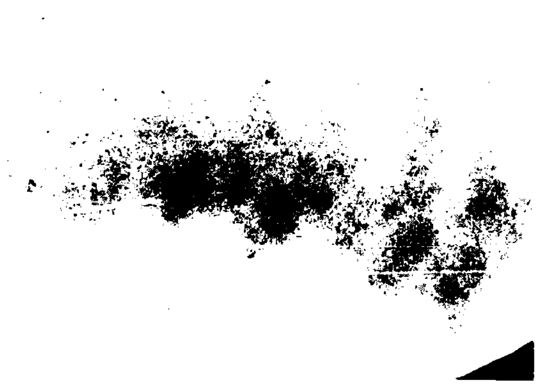
d. After 5 years and 7 months.

e. After 6 years and 8 months.

Figure 7. Photomacrographs for System 1, catalyzed silicone.

a. Before exposure.

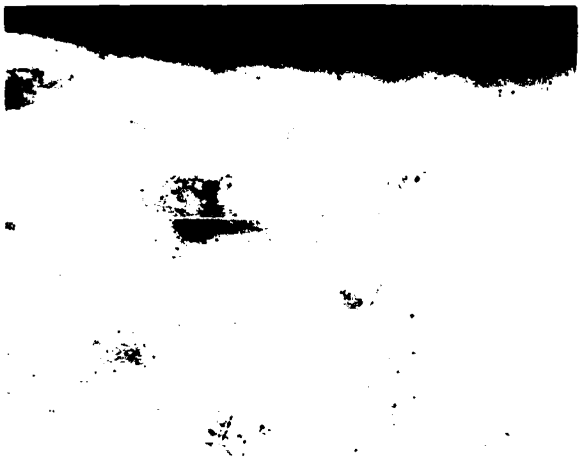
b. After 1 year and 3 months.



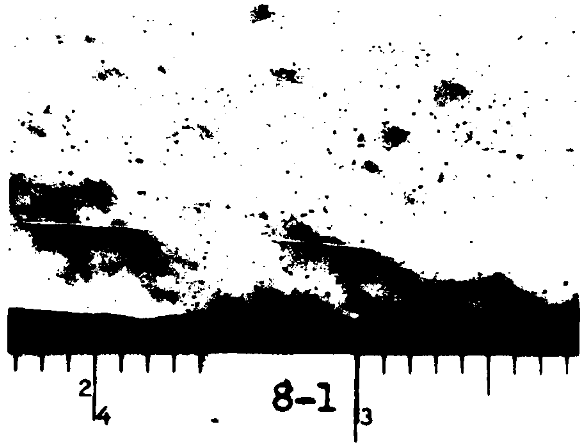
c. After 3 years and 3 months.

d. After 7 years and 10 months.

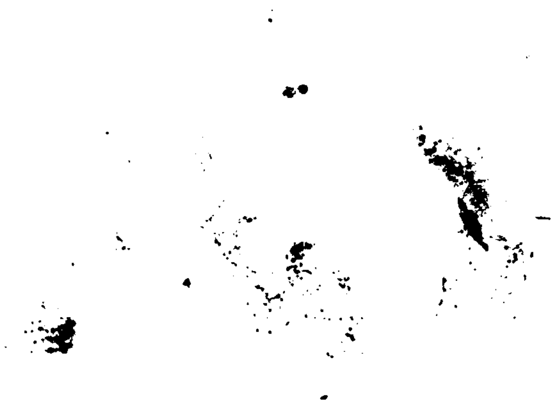
Figure 8. Photomacrographs for System 13, catalyzed urethane.



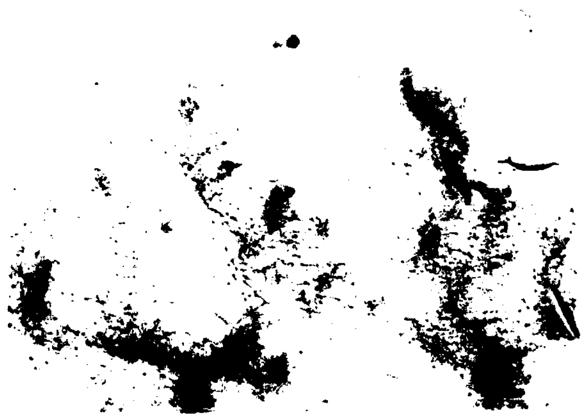
a. Before exposure.



b. After 1 year and 3 months.



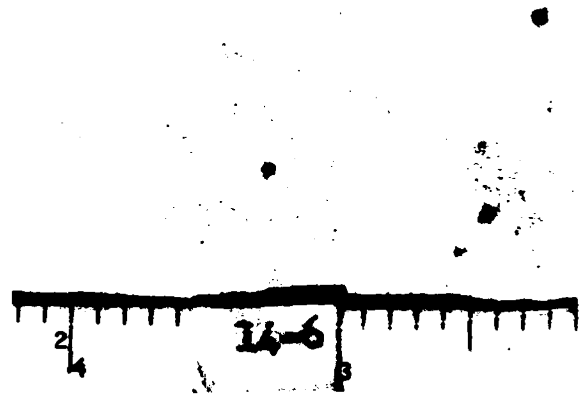
c. After 4 years and 10 months.



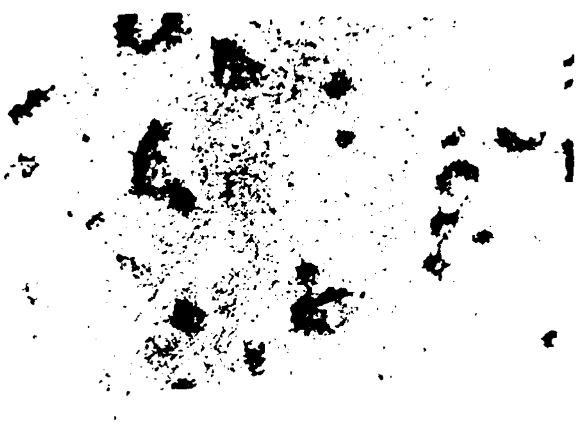
d. After 6 years and 8 months.

Figure 9. Photomacrographs of System 8, catalyzed butyl.

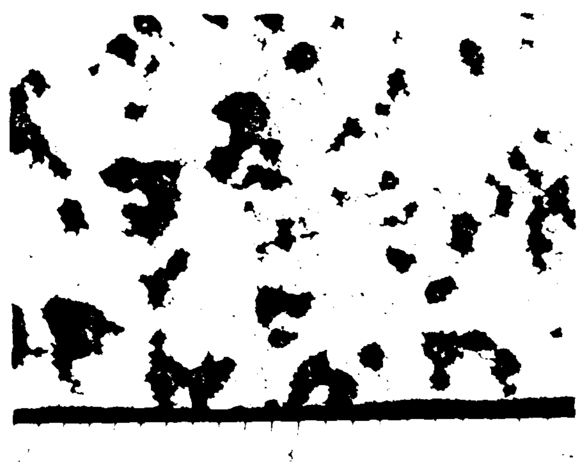
a. Before exposure.



b. After 1 year and 1 month.



c. After 2 years and 7 months.



d. After 3 years and 1 month.

Figure 10. Photomacrographs of System 14, moisture-curing urethane.

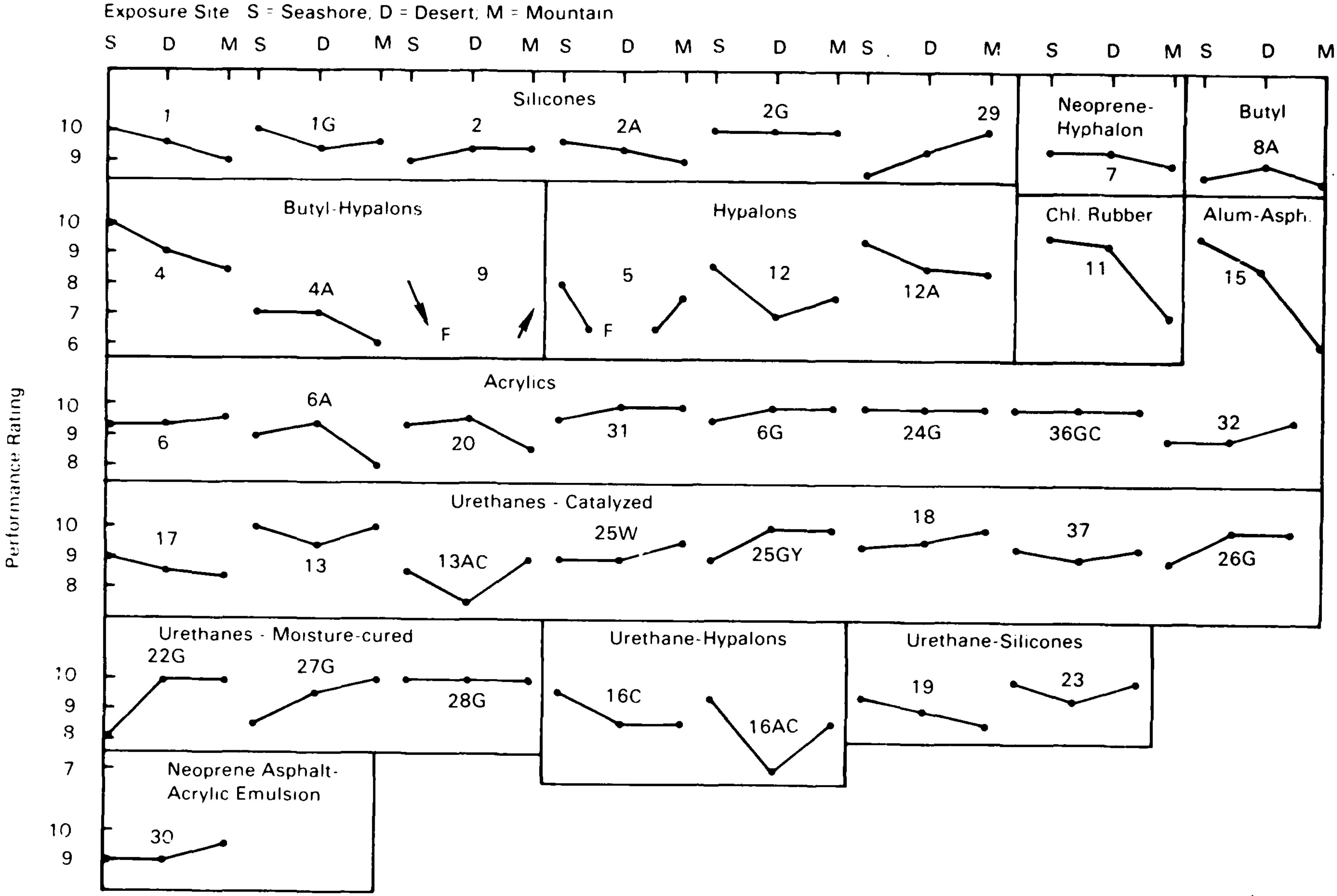


Figure 11. Effects of exposure site on performance.

Appendix A

FOAM AND COATING MATERIAL NAMES AND SOURCES

PUF MATERIAL

Priorietary Name	Source
A. CPR Upjohn 485-2 (2 pcf) B. CPR Upjohn 485-2.5 (2.5 pcf) C. CPR Upjohn 485-3 (3.0 pcf)	CPR Division, The Upjohn Co. (Now Dow Chemical USA Urethanes Department Midland, Michigan 48674) Note: Dow Chemical no longer markets spray foam systems.
D. FSC - 21 - (2.0 pcf) E. FSC - 26 - 3 (3.0 pcf) FSC - 234 - 3 (3.0 pcf)	Foam Systems Co. Riverside, CA 92507 (This company is no longer in business.)
G. Isofoam SS - 00125A/00126B (3.0 pcf)	Witco Chemical Corp. (Now Isocyanate Products Inc. 900 Wilmington Road New Castle, DE 19720)
H. PDL Thermaster (2.0 pcf)	Polymer Development Laboratories, Inc. 212 W. Taft Ave. Orange, CA 92665
I. SWD - 525 (2.5 pcf)	Southwest Distributing Co. P.O. Box 1422 Mesa, AZ 85201
J. Utah 125 - 4S (3.0 pcf)	Utah Foam Products, Inc. 527 So. 2165 West Salt Lake City, UT 84104
K. Polyfoam 251 (2.5 pcf)	Anchor Foam Systems, Inc. Waukesha, WI 53187 (This company is no longer in business.)
L. Brand of foam unknown	
M. Carpenter C290 (3.0 pcf)	Carpenter Insulation and Coatings Co. 443 Bronz Way Dallas, TX 75236

COATING MATERIALS

Coating System No.	Source
1. Silicone weather coatings 3308/W501C base coat, medium gray 3304/W3007C topcoat, cement gray	Silicone Products Department General Electric Company Waterford, New York 12188 (A)*
2. 3-5000 Construction Coating 2G. Gray base coat White topcoat	Dow Corning Corporation Midland, Michigan 48640 (A)
3. U.S. Polymeric PC8105 butyl base coat PC8204 hypalon topcoat	U.S. Polymeric Santa Ana, California 92707 (A) (This company is no longer in business)
4. Elastron Elastron No. 858 butyl base coat Elastomir No. 35 hypalon topcoat	United Coatings 1130 E. Sprague Ave. Spokane, Washington 99202 (A)
5. *Monolar mastic* No. 6036	Foster Division Amchem Products, Inc. Ambler, Pennsylvania 19002 (A)
6. Diathon	United Coatings 1130 E. Sprague Ave. Spokane, Washington 99202 (A)
7. Gaco-Flex N118 neoprene base coat H-10 hypalon topcoat	Gates Engineering Company Wilmington, Delaware (A)
8. Vapalon No. 6126 Aluminum-gray (Coating no longer available)	Exxon Chemical Company USA 8230 Stedman Street Houston, Texas 77029 (A)
9. Chem-Elast 5011 butyl base coat 5501 hypalon topcoat	PlasChem Coatings P.O. Box 197909 St. Louis, Missouri 63144 (A)
10. Roof-Flex Roof-flex 156	Carboline Roofing Products Division 350 Hanley Industrial Ct. St. Louis, Missouri 63144 (A)

11.	Elastomeric Roof Coating 83011	The FlintKote Company East Rutherford, NJ 07073 (A) (This company is no longer in business.)
12.	GacoFlex Hypalon H2500	GacoWestern, Inc. P.O. Box 88698 Seattle, Washington 98188 (A)
13.	Weather/Flex Plus Irathane 300 base coat Irathane 394 topcoat	Irathane Systems Industrial Park Hibbing, Minnesota 55746 (A)
14.	ElastoDeck ElastoDeck 5001	Pacific Polymers 15801 Moran Street Unit E Westminster, California 42683 (A)
15.	Alumination Permaroof base coat Alumination 301 topcoat	Republic Powdered Metals 2628 Pearl Road Medina, Ohio 44256 (A)
16. 16A.	Weather/Flex Irathane 300 base coat Irathane 157 topcoat	Irathane Systems Industrial Park Hibbing MN 55746 (A,C)
17.	Roof-Flex Roof-flex 145 base coat Roof-flex 156 topcoat	Carboline, Roofing Products Division 350 Hanley Industrial CT St. Louis, MO 63144 (G)
18.	Gaco U-66 U - 66 base and topcoats	Gaco-Western, Inc. P.O. Box 88698 Seattle, WA 98188 (G)
19.	3-5000 Construction Coating Gaco U - 66 base coat	Gaco-Western, Inc. P.O. Box 88698 Seattle, WA 98188
	White 3-5000 Construction Coating topcoat	Dow Corning Corporation Midland, MI (G)
20.	A-5400 White base and topcoat	Gaco-Western, Inc. P.O. Box 88698 Seattle, WA 98188 (G)
21.	Thorotherm White base and topcoat	Thoro System Products 7800 N.W. 38th St. Miami, FL 33166 (B)

22G.	H.E.R. Tan base and topcoat Light gray granules (Coating no longer available.)	Contech.Sonneborn Roofing Products Division 711 Computor Ave. Minneapolis, MN 55435 (G)
23.	3-5000 Construction Coating Tan base coat	Contech.Sonneborn Roofing Products Division 711 Computor Ave. Minneapolis, MN 55435
	White 3-5000 Construction Coating topcoat	Dow Corning Corporation Midland, MI 48640 (G)
24G.	SWD White SWD acrylic base and topcoats	Southwest Distributing Co. P.O. Box 1422 Mesa, AZ 85201 (I)
25.	Ureflex Off-white Ureflex base coat White Ureflex topcoat	Foam Systems Co. Riverside, CA (D) (This company is no longer in business.)
26G.	Ureflex Off-white Ureflex base and topcoats with green granules	Foam Systems Co. Riverside, CA (D) (This company is no longer in business.)
27.	XB-5796 Aluminum XB-5796 base and topcoats (Coating no longer available)	3M Adhesives and Sealers Division St. Paul, MN 55101 (L)
28G.	XA5762/XG5724 Gray XA5762 base coat and gray XG5724 topcoat with green granules (Coating no longer available)	3M Adhesives and Sealers Division St. Paul, MN 55101 (L)
29.	3-5035 Construction Coating Light gray 3-5035 base and topcoats (coating no longer available)	Dow Corning Corporation Midland, MI (G)
30.	Liquid Boot Black liquid boot base coat, white acrylic topcoat	ACI Buena Park, CA (G) (This company is no longer in business.)
31.	Acryflex White Acryflex base and topcoats	Foam Systems Co. Riverside, CA (D) (This company is no longer in business.)

32.	Chem-Elast Green Chem-Elast acrylic base and topcoat	Chem-Elast Coatings, Inc. P.O. Box 197909 St. Louis, MO 63144 (D)
33.	Hydrotherm Brown Hydrotherm 2000 base coats, white Hydrotherm topcoat	ACI Buena Park, CA (L) (This company is no longer in business.)
34.	Hydrotherm Brown Hydrotherm 2000 base and topcoat	ACI Buena Park, CA (L) (This company is no longer in business.)
35GC.	A-5400 White A-5400 base and topcoat with gray granules	Gaco-Western, Inc. P.O. Box 88698 Seattle, WA 98188 (J)
36GC.	Rapid Roof White Rapid Roof base and topcoats with granules	Conklin Company, Inc. 4660 West 77th St. Minneapolis, MN 55435 (B)
37.	Elastroperm E-300 Aluminum Elastroperm E-300 base coat and white Elastroperm topcoat	Coatings for Industry 319 Township Line Road Souderton, PA 18964 (L)
38.	Ureflex 100/200 Brown Ureflex 100 base coats, and white Ureflex 200 topcoat	Foam Systems Co. Riverside, CA (E) (This company is no longer in business.)
39.	Tufcon Black fibrated asphalt base coat #10 grit granite embedded in base coat White cementitious topcoat	Hutchison Roofing Co. 7096 Broadway Lemon Grove, CA 92045 (I)
40.	Rimspray Brown Rimspray base coat White PDL topcoat (Coating no longer available)	Polymer Development Laboratories, Inc. 212 W. Taft Ave. Orange, CA 92665 (H)
41.	Futura-Thane/Futura-flex Tan Futura-thane 524 base coat White Futura-flex 550 topcoat	Futura Coatings, Inc. 9200 Latty Ave. Hazelwood, MO 63042 (L)
42.	1XF5761/PD5796 Aluminum 1XF5796 base coat Aluminum PD5796 topcoat (Coatings no longer available)	3M Adhesives and Sealers Division St. Paul, MN 55101 (L)

43.	Sunshield White Sunshield 790A 6016 base and topcoats	Anchor Coatings, Inc. [Now owned and operated by: Gaco-Western, Inc. P.O. Box 88698 Seattle, WA 98188 (K)]
44.	Ure-base/Ure-cap Light gray Ure-base 6001 base coat White Ure-cap 6000 topcoat	Anchor Coatings, Inc. [Now owned and operated by: Gaco-Western, Inc. P.O. Box 88698 Seattle, WA 98188 (K)]
45.	Ureflex 150/2001 Brown Ureflex 150 base coat White Ureflex 2001 topcoat	Foam Systems Co. Riverside, CA (E) (This company is no longer in business.)
46.	Ure-base/Aro-shield Light gray Ure-base 6001 base coat White Aro-shield 6002 topcoat	Anchor Coatings, Inc. [Now owned and operated by: Gaco-Western, Inc. P.O. Box 88698 Seattle, WA 98188 (K)]
47.	Armor-shield/Aro-shield Black Armor-shield 7000 base coat White Aro-shield 6002 topcoat	Anchor Coatings, Inc. [Now owned and operated by: Gaco-Western, Inc. P.O. Box 88698 Seattle, WA 98188 (K)]
48.	Ure-shield Aluminum Ure-shield 6006 base and topcoats	Anchor Coatings, Inc. [Now owned and operated by: Gaco-Western, Inc. P.O. Box 88698 Seattle, WA 98188 (K)]
49.	Ure-shield/Ure-phatic Aluminum Ure-shield 6006 base coat White Ure-phatic 6008 topcoat	Anchor Coatings, Inc. [Now owned and operated by: Gaco-Western, Inc. P.O. Box 88698 Seattle, WA 98188 (K)]
50.	Futura-thane/Futura-flex Brown Futura-thane 5000 base coat White Futura-thane 5550 topcoat	Futura Coatings, Inc. 9200 Latty Ave. Hazelwood, MO 63042 (L)
51.	Silicone 7850 White silicone 7850 base and topcoats	The Neogard Corporation 6900 Maple Ave. Dallas, TX 75235 (M)

52. Permathane TC FR
Gray Permathane TC FR 70500 series base/intermediate coats
White Permathane TC FR 70500 series topcoat

The Neogard Corporation
6900 Maple Ave.
Dallas, TX 75235 (M)

53. Permathane TC A FR
Gray Permathane TC A FR 70500 series base/intermediate coats
White Aliphatic 7491/7955 topcoat

The Neogard Corporation
6900 Maple Ave.
Dallas, TX 75235 (M)

54. Permathane FR
Black Permagard 7419 base and intermediate coats
White Permathane 7443 second intermediate and topcoats

The Neogard Corporation
6900 Maple Ave.
Dallas, TX 75235 (M)

*The letter in parenthesis following the coating materials source and address refers to the particular foam used with that coating system (see listing of PUF material above). Where more than one foam was used with a particular coating system, all foams are listed.

Appendix B

INVESTIGATIONS CONDUCTED BY U.S. BUREAU OF RECLAMATION

At the request of NCEL, field and laboratory tests were made on PUF panels with selected coating systems supplied by NCEL.

Field Tests

Coated PUF panels were placed at the USBR laboratory exposure site at Denver, Colorado and also at the Weld substation at Greeley, Colorado, which is an area frequently subjected to moderate hail. Results of the tests after exposure of 3 years at the Denver site and 1 year at the Greeley site are shown in Table B-1. USBR personnel did not use the same performance evaluations as did NCEL personnel, so the results are stated by word descriptions.

Silicones. At the Denver site, System 2 showed poor adhesion and it was subjected to severe bird pecking. Its general condition was fair. At the Greeley site, System 2 was also subjected to bird pecking but had good adhesion. It should be noted that the panel at Greeley had been there only 1 year.

At the Denver site, System 29 was also subjected to severe bird pecking, showed poor adhesion, and was in fair condition. At the Greeley site, System 29 had light pinholes, one bird peck, and poor adhesion.

Butyl-Hypalon. At the Denver site, System 9 exhibited many small pinholes and showed minor hail damage and good adhesion. Its general condition was fair. System 29 showed severe pinholes, much craying, and fair adhesion.

Acrylics. System 6 had minor hail damage at the Denver site and few pinholes. It showed fair adhesion and was in good condition. At the Greeley site, System 6 has many pinholes, splits in the valleys, and fair to poor adhesion.

At the Denver site, System 31 exhibited minor bird pecking, had fair adhesion, and was in good condition. At the Greeley site, System 31 had very light surface pinholes and fair adhesion.

At the Denver site, System 35 showed small pinholes, moderate bird pecking, and good adhesion. It was considered to be in fair condition. At the Greeley site, System 35 showed many large pinholes and had fair adhesion.

Fibrated Aluminum-Asphalt. At the Denver site, System 15 had minor hail damage, and showed minor bird pecking and fair adhesion. It was considered to be in poor condition. At the Greeley site, System 15 had damage from small hailstones but had good adhesion.

Urethanes. At the Denver site, System 13 showed small pinholes, slight hail damage, good adhesion, and was considered to be in good condition. At the Greeley site, System 13 exhibited pinholes in the valley, one bird peck, and fair to poor adhesion.

System 38 had few pinholes and good adhesion at the Denver site. It was considered to be in excellent condition. At the Greeley site, System 38 showed light surface pinholes and good adhesion.

Laboratory Tests

The objective of the laboratory study was to determine the glass transition temperature (T_g) of each coating. The glass transition temperature is the temperature at which an elastomeric material becomes a brittle material. If an otherwise elastomeric coating should become brittle at a to-be-expected low temperature, it would be subject to cracking from either hailstones or foot traffic as well as temperature contractions.

Tests to determine T_g were done by the impact method and also by using a Perkin-Elmer Differential Scanning Calorimeter (DSC). T_g determined by the DSC is much more precise than it is when determined by the impact method. Not much work has been done to correlate the two methods. T_g by the impact method would be determined by plotting the impact strength of the material versus the temperature, over the temperature range in question. The T_g would be the temperature at which the impact strength took a sudden drop, as shown in Figure B-1. Impact methods have an inherent dependence on coating thickness, which is significant in this study because the PUF coatings not only vary in thickness but also have hidden flaws. T_g by the DSC method has no dependence on coating thickness.

Results are presented in Table B-2. The correlation between the two test methods is good with the exception of the silicones, which is explained in the footnote.

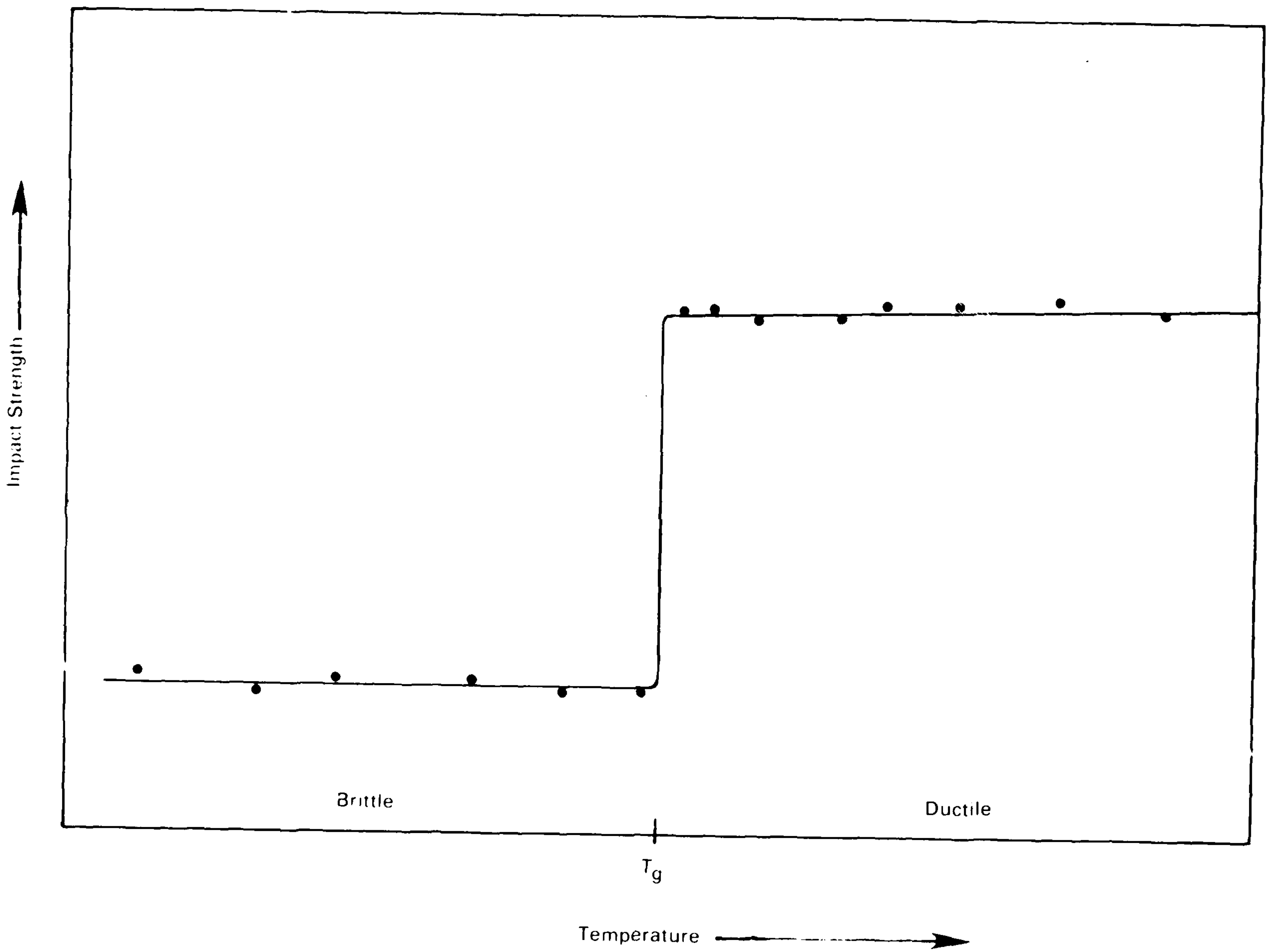


Figure B-1. Typical plot for determining T_g by the impact method.

Table B-1. Results of Exposure Tests Conducted by USBR

Coating Description	System Number	Exposure Site and Time	
		Denver 3 Years	Greeley 1 Year
Silicone	2	Severe bird pecking, poor adhesion, fair condition.	One bird peck; good adhesion.
	29	Severe bird pecking, poor adhesion, fair condition.	Light surface pinholes; one bird peck; poor adhesion.
Butyl-Hypalon	9	Many small pinholes; minor hail damage; good adhesion; fair	Severe pinholes; much crazing; fair adhesion.
Acrylics	6	Minor hail damage; few pinholes; fair adhesion; good condition.	Many pinholes; splits in valleys; fair to poor adhesion.
	31	Minor bird pecking; fair adhesion; good condition.	Very light surface pinholes; fair adhesion.
	35	Small pinholes; mcderate bird pecking; fair adhesion; poor condition.	Many large pinholes; fair adhesion.
Fibrated Aluminum-Asphalt	15	Moderate hail damage; minor bird pecking; fair adhesion; poor condition.	Damage from small hailstones; good adhesion.
Urethanes	13	Small pinholes; slight hail damage; good adhesion; good condition.	Pinholes in valleys; one bird peck; fair to poor adhesion.
	38	Few pinholes; good adhesion; excellent condition.	Light surface pinholes; good adhesion.

Table B-2. Results of Glass Transition Temperature Tests by USBR

Coating Description	System Number	Coating Thickness (mils)	DSC Initial T_g °F	DSC 1 Year T_g °F	DSC 3 Years T_g °F	Impact 3 Years T_g °F
Silicones	2	20	-189	-189	-186	-95[a]
	29	15	-189	-189	-190	-95[a]
Butyl-Hypalon	9	30	-78	-85	-78	-88
Acrylics	6	32	39	42	50	31
	31	34	-12	-9	-8	-19
	35	26	-29	-29	-18	-43
Fibrated Aluminum Asphalt	15	44	24	20	7	4
Urethanes	13	19	-67	-65	-65	-60[b]
	38	45	14	8	12	4

[a]The lowest temperature available was -95°F; there was no failure at -95°F.

[b]This was the only material where the T_g found by the low temperature impact test was higher than the T_g determined with the DSC. This could be related to fact that this material exhibits a second glass transition at a higher temperature.

DISTRIBUTION LIST

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AF / 6550 ABG/DER, Patrick AFB, FL
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AFB / 42 CES/Ready Officer, Loring AFB, ME
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AFESC / DEMM/Ius, Tyndall AFB, FL
AFESC / TIC Lib, Tyndall AFB, FL
AFSC / DEEQ (P. Montoya), Peterson AFB, CO
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ARMY / HQ Europe Command, AEAEN-FE-U, Heidelberg, GE, APO New York,
ARMY / HQDA (DAEN-ZCM), Washington, DC
ARMY / Kwajalein Atoll, BMDSC-RKL-C, APO San Francisco,
ARMY / POJED-O, APO San Francisco,
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ARMY CERL / CERL-ES (Lawrie), Champaign, IL
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ARMY CRREL / CRREL-EC (Flanders), Hanover, NH
ARMY CRREL / CRREL-EG (Eaton), Hanover, NH
ARMY CRREL / Iskandar, Hanover, NH
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ARMY DEPOT / Letterkenny, SDSLE-SF, Chambersburg, PA
ARMY EHA / HSHB-EA-S, Aberdeen Proving Ground, MD
ARMY EHA / HSHB-EW, Aberdeen Proving Ground, MD
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ARMY ENGRG DIST / Lib, Seattle, WA
ARMY ENGRG DIST / Lib, Portland, OR
ARMY ENGRG DIST / LMVCO-A/Bentley, Vicksburg, MS
ARMY ENGRG DIST / Phila, Lib, Philadelphia, PA
ARMY ENGRG DIV / ED-SY (Loyd), Huntsville, AL
ARMY ENGRG DIV / HNDED-SY, Huntsville, AL
ARMY EWES / Lib, Vicksburg, MS
ARMY EWES / WESCD (TW Richardson), Vicksburg, MS
ARMY EWES / WESCD-P (Melby), Vicksburg, MS
ARMY EWES / WESCW-D, Vicksburg, MS
ARMY EWES / WESGP-E, Vicksburg, MS
ARMY HHC / 7th ATC, Grafenwohr, GE, APO New York,
ARMY LMC / Ft. Lee, VA
ARMY MMRC / DRXMR-SM (Lenoe), Watertown, MA
ARMY MTMC / MTT-CE, Newport News, VA
ARMY TRANS SCH / ATSP-CDM (Civilla), Fort Eustis, VA
ARVID GRANT & ASSOC / Olympia, WA
ATLANTIC RICHFIELD CO / RE Smith, Dallas, TX
BABCOCK & WILCOX CO / Tech Lib, Barberton, OH
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BATTELLE / D. Frink, Columbus, OH
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CBC / Code 155, Port Hueneme, CA
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CBC / Code 470.2, Gulfport, MS
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CHAO, JC / Houston, TX
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CITY OF LIVERMORE / Dackins, PE, Livermore, CA
CITY OF MONTEREY / Const Mgr (Reichmuth), Monterey, CA
CLARK, T. / Redding, CA
CLARKSON COLL OF TECH / CE Dept, Potsdam, NY
CNO / DCNO, Logs, OP-424C, Washington, DC
COASTAL SCI & ENGRG / C Jones, Columbia, SC
COGUARD R&D CEN / Lib, Groton, CT
COLLINS ENGRG, INC / M Garlich, Chicago, IL
COLORADO STATE UNIV / CE Dept (Criswell), Ft. Collins, CO
COLUMBIA GULF TRANSMISSION CO / Engrg Lib, Houston, TX
COM GEN FMF / LANT, SCE, Norfolk, VA
COM GEN FMF / PAC, SCIAD (G5), Camp HM Smith, HI
COM GEN FOURTH MARDIV / Base Ops, New Orleans, LA

COMCBLANT / Code S3T, Norfolk, VA
COMDT COGUARD / Lib, Washington, DC
COMFLEACT / PWO, FPO Seattle,
COMFLEACT / PWO, FPO Seattle,
COMFLEACT / SCE, FPO Seattle,
COMNAVACT / G.T. Clifford, London, UK, FPO New York,
COMNAVACT / PWO, London, UK, FPO New York,
COMNAVAIR / Lant, Nuc Wpns Sec Offr, Norfolk, VA
COMNAVAIRSYSCOM / AIR-714, Washington, DC
COMNAVAIRSYSCOM / Code 422, Washington, DC
COMNAVLOGPAC / Code 4318, Pearl Harbor, HI
COMNAVMARIANAS / Code N4, FPO San Francisco,
COMNAVRESFOR / Code 08, New Orleans, LA
COMNAVRESFOR / Code 823, New Orleans, LA
COMNAVSUPPFORANTARCTICA / DET, PWO, FPO San Francisco,
COMOCEANSYS / PAC, SCE, Pearl Harbor, HI
CONSOER TOWNSEND & ASSOC / Schramm, Chicago, IL
CONTINENTAL OIL CO / O. Maxson, Ponca City, OK
CORNELL UNIV / Civil & Environ Engrg, Ithaca, NY
CORNELL UNIV / Lib, Ithaca, NY
CORRIGAN, LCDR S. / USN, CEC, Stanford, CA
COULTRAP CONSULTING SERVICES / Keith Coultrap, Tempe, AZ
DAVY DRAVO / Wright, Pittsburg, PA
DAY ZIMMERMAN/BASIL CORP / Fitzgerald, Hawthorne, NV
DE PALMA, J R. / Picayune, MS
DEPT OF LABOR / Job Corps, (Mann), Imperial Beach, CA
DEPT OF STATE / Foreign Bldgs Ops, BDE-ESB Arlington, VA
DFSC / OWE, Alexandria, VA
DILLINGHAM CONSTR CORP / (HD&C), F McHale, Honolulu, HI
DOD / DFSC-FE, Alexandria, VA
DODDS / PAC, FAC, FPO Seattle,
DOE / Wind/Ocean Tech Div, Port Tobacco, MD
DTIC / Alexandria, VA
DTRCEN / Code 284, Annapolis, MD
DTRCEN / Code 4120, Annapolis, MD
DTRCEN / Code 522, Annapolis, MD
DTRCEN / Commander, Bethesda, MD
DTRCEN / Commander, Bethesda, MD
DTRCEN / Commander, Bethesda, MD
DTRCEN / Commander, Bethesda, MD
DUKE UNIV / CE Dept (Muga), Durham, NC
DURLACH, O'NEAL, JENKINS & ASSOC / Columbia, SC
EARL & WRIGHT CONSULTING ENGRGS / Jensen, San Francisco, CA
EASTPORT INTL, INC / JH Osborn, Mgr, Ventura, CA
EDWARD K NODA & ASSOC / Honolulu, HI
ENERCOMP / Amistadi, Brunswick, ME
EPA / Reg VIII Lib, Denver, CO
ESCO SCIENTIFIC PRODUCTS (ASIA) / PTE LTD, , Singapore
EVALUATION ASSOC, INC / M.A. Fedele, King of Prussia, PA
FAA / Code APM-740 (Tomita), Washington, DC
FACTORY MUTUAL ENGINEERING / Hankins, Charlotte, NC
FISHER, R / San Diego, CA
FLORIDA INST OF TECH / CE Dept (Kalajian), Melbourne, FL
FOREST INST FOR OCEAN & MT / Lib, Carson City, NV
FOWLER, J.W. / Virginia Beach, VA
GARD INC / LB Holmes, Niles, IL
GDM & ASSOC, INC. / Fairbanks, AK
GENERAL DYNAMICS / D-443 (Leone), Groton, CT
GEOTECHNICAL ENGRS, INC / Murdock, Winchester, MA
GIANNOTTI & ASSOC, INC / Annapolis, MD
GIDEP / OIC, Corona, CA
GLIDDEN CO / Rsch Lib, Strongsville, OH
GOVERNOR'S ENERGY OFFICE / Hyland, Concord, NH
GSA / Code Engrg Branch, PQB, Washington, DC
GSA / Code PCDP, Washington, DC
GULATI, RIPU / Rockville, MD
HALEY & ALDRICH, INC. / T.C. Dunn, Cambridge, MA
HANDLEY, DM / Gulf Breeze, FL
HARDY, S.P. / San Ramon, CA
HARTFORD STEAM BOILER INSP & INS CO / Spinelli, Hartford, CT
HAYNES & ASSOC / H. Haynes, PE, Oakland, CA
HAYNES, B / N Stonington, CT
HENRICO CO. GEN SVCS / JW Warren, Richmond, VA
HERONEMUS, W.E. / Amherst, MA
HIRSCH & CO / L Hirsch, San Diego, CA
HQ AFESC/DE / Firman, Tyndall AFB, FL
HUD/FHA / Office of Architecture and Engineering Standards, Washington, DC
INSPEC, INC. / Jennings, Minneapolis, MN
INST OF MARINE SCIENCES / Dir, Morehead City, NC
INST OF MARINE SCIENCES / Lib, Port Aransas, TX
INSULATED ROOFING CONTRACTORS / Irwin H. Stumler, Louisville, KY
INTL MARITIME, INC / D. Walsh, San Pedro, CA
IOWA STATE UNIV / Arch Dept (McKrown), Ames, IA
IRE-ITTD / Input Proc Dir (R. Danford), Eagan, MN
JOHNSON CONTROLS, INC / Trng Dept, Milwaukee, WI
JOUR OF DEF / C. Wallach, Ed, Canoga Park, CA
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MARCORBASE / Code 4.01, Camp Pendleton, CA
MARCORBASE / Facilities Coordinator, Camp Pendleton, CA
MARCORBASE / Maint Offr, Camp Pendleton, CA
MARCORBASE / PAC, FE, FPO Seattle,
MARCORBASE / PAC, PWO, FPO Seattle,
MARCORBASE / PWO, Camp Pendleton, CA
MARCORBASE / PWO, Camp Lejeune, NC
MARCORDIST / 12, Code 4, San Francisco, CA
MARCORPS / FIRST FSSG, Engr Supp Offr, Camp Pendleton, CA
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MC DERMOTT, INC / E&M Div, New Orleans, LA
MCAS / Code 1JE.50 (Meyer), Santa Ana, CA
MCAS / Code 6EDD, FPO Seattle,
MCAS / Code LCU, Cherry Point, NC
MCAS / El Toro, Code 1JD, Santa Ana, CA
MCLB / Code 555, Albany, GA
MCLB / PWC (Sachan), Barstow, CA
MCRDAC / AROICC, Quantico, VA
MCRDAC / M & L Div, Quantico, VA
MCRDAC / Mech Engrg Mgr, Quantico, VA
MCRDAC / NSAP Rep, Quantico, VA
MCRDAC / PWD, Quantico, VA

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MILLER, R.W. / San Diego, CA
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MIT / Engrg Lib, Cambridge, MA
MIT / Lib, Tech Reports, Cambridge, MA
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MOFFATT & NICHOL ENGRS / R. Palmer, Long Beach, CA
MT DAVISSON / CE, Savoy, IL
NAF / Dir, Engrg Div, PWD, FPO Seattle,
NAF / PWO, FPO Seattle,
NALF / OIC, San Diego, CA
NAS / Chase Fld, Code 18300, Beeville, TX
NAS / Code 072E, Willow Grove, PA
NAS / Code 163, Keflavik, Iceland, FPO New York,
NAS / Code 183, Jacksonville, FL
NAS / Code 1833, Corpus Christi, TX
NAS / Code 18700, Brunswick, ME
NAS / Code 22, Patuxent River, MD
NAS / Code 6234 (C. Arnold), Point Mugu, CA
NAS / Code 70, Marietta, GA
NAS / Code 725, Marietta, GA
NAS / Code 8, Patuxent River, MD
NAS / Code 83, Patuxent River, MD
NAS / Fac Mgmt Offc, Alameda, CA
NAS / Lead CPO, PWD, Self Help Div, Beeville, TX
NAS / Memphis, PWO, Millington, TN
NAS / Miramar, Code 1821A, San Diego, CA
NAS / Miramar, PWO, San Diego, CA
NAS / Miramar, PWO, Code 187, San Diego, CA
NAS / NI, Code 183, San Diego, CA
NAS / P&E Supr, FPO Seattle, WA
NAS / PW Engrg, Patuxent River, MD
NAS / PWD Maint Div, New Orleans, LA
NAS / PWO, FPO Seattle, WA
NAS / PWO, Cecil Field, FL
NAS / PWO, New Orleans, LA
NAS / PWO, Willow Grove, PA
NAS / PWO, Kingsville, TX
NAS / PWO, Moffett Field, CA
NAS / PWO, Bermuda, FPO New York,
NAS / PWO, Keflavik, Iceland, FPO New York,
NAS / PWO, Sigonella, Italy, FPO New York,
NAS / Whidbey Is, PW-2, Oak Harbor, WA
NAS / Whiting Fld, PWO, Milton, FL
NAS/ Memphis, Dir, Engrg Div, Millington, TN
NATIONAL BUREAU OF STANDARDS / Building Materials Division, Gaithersburg, Md
NATIONAL BUREAU OF STANDARDS / Robert Mathey, Gaithersburg, MD
NATIONAL ROOFING CONTRACTORS ASSOCIATION / Robert Lacosse, Rosemont, IL
NATL ACADEMY OF SCIENCES / NRC, Naval Studies Bd, Washington, DC
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NAVAIRPROPCEN / CO, Trenton, NJ
NAVAIRTESTCEN / PWO, Patuxent River, MD
NAVAL ED & TRAIN CEN / Code 42, Newport, RI
NAVAL ED & TRAIN CEN / PWO, Newport, RI
NAVAL ED & TRAIN CEN / Util Dir, Newport, RI
NAVAL WAR COLLEGE / Code 24, Newport, RI
NAVAUDSVCHQ / Dir, Falls Church, VA
NAVAVIONICCEN / Code D-701, Indianapolis, IN
NAVAVIONICCEN / PWO, Indianapolis, IN
NAVAVNDEPOT / Code 61000, Cherry Point, NC
NAVAVNDEPOT / Code 61000, Pensacola, FL
NAVAVNDEPOT / Code 640, Pensacola, FL
NAVCAMS / SCE, Wahiawa, HI
NAVCAMS / WESTPAC, SCE, FPO San Francisco,
NAVCOASTSYSCEN / CO, Panama City, FL
NAVCOASTSYSCEN / Code 2360, Panama City, FL
NAVCOASTSYSCEN / Code 423, Panama City, FL
NAVCOASTSYSCEN / Code 715 (J. Mittleman), Panama City, FL
NAVCOASTSYSCEN / Tech Lib, Panama City, FL
NAVCOMM DET / MED, SCE, Sigonella, Italy, FPO New York,
NAVCOMMSTA / Code 401, Nea Makri, Greece, FPO New York,
NAVCOMMSTA / PWO, Thurso, UK, FPO New York,
NAVCONSTRACEN / Code B-1, Port Hueneme, CA
NAVCONSTRACEN / Code D2A, Port Hueneme, CA
NAVCONSTRACEN / Code T12, Gulfport, MS
NAVEODTECHCEN / Tech Lib, Indian Head, MD
NAVFAC / LANTDIV Code 102, Larry Hershi, Norfolk, VA
NAVFAC / LANTDIV Code 401, Les Toler, Norfolk, VA
NAVFAC / N62, Argentina, NF, FPO New York,
NAVFAC / NORTHDIV Code 102A, Tom Wallace, Philadelphia, PA
NAVFAC / PACDIV Code 102, Minato, Pearl Harbor, HI
NAVFAC / PWO, Oak Harbor, WA
NAVFAC / SOUTHDIV Code 102, Mark De Ogburn, Charleston, SC
NAVFAC / WESTDIV Code 102, Robert Deaver, San Bruno, CA
NAVFACENGCOM / Code 03, Alexandria, VA
NAVFACENGCOM / Code 03T (Essoglou), Alexandria, VA
NAVFACENGCOM / Code 04A, Alexandria, VA
NAVFACENGCOM / Code 04A1, Alexandria, VA
NAVFACENGCOM / Code 04A1D, Alexandria, VA
NAVFACENGCOM / Code 04A3, Alexandria, VA
NAVFACENGCOM / Code 04A3C, Alexandria, VA
NAVFACENGCOM / Code 04B3, Alexandria, VA
NAVFACENGCOM / Code 051A, Alexandria, VA
NAVFACENGCOM / Code 0631, Alexandria, VA
NAVFACENGCOM / Code 083, Alexandria, VA
NAVFACENGCOM / Code 09M124 (Lib), Alexandria, VA
NAVFACENGCOM / Code 1002B, Alexandria, VA
NAVFACENGCOM / Code 163, Alexandria, VA
NAVFACENGCOM / Code 1651, Alexandria, VA
NAVFACENGCOM CHESDIV / Code 112.1, Washington, DC
NAVFACENGCOM CONTRACTS / AROICC, Coleville, CA
NAVFACENGCOM CONTRACTS / AROICC, Quantico, VA
NAVFACENGCOM CONTRACTS / Code 923, Everett, WA
NAVFACENGCOM CONTRACTS / DROICC, Lemoore, CA
NAVFACENGCOM CONTRACTS / DROICC, Santa Ana, CA
NAVFACENGCOM CONTRACTS / North Bay, Code 1042.AA, Vallejo, CA
NAVFACENGCOM CONTRACTS / OICC, FPO San Francisco,
NAVFACENGCOM CONTRACTS / OICC, FPO San Francisco,
NAVFACENGCOM CONTRACTS / OICC/ROICC, Virginia Beach, VA
NAVFACENGCOM CONTRACTS / ROICC (Code 495), Portsmouth, VA
NAVFACENGCOM CONTRACTS / ROICC, Corpus Christi, TX
NAVFACENGCOM CONTRACTS / ROICC, Jacksonville, FL
NAVFACENGCOM CONTRACTS / ROICC, Twentynine Palms, CA
NAVFACENGCOM CONTRACTS / ROICC, Crane, IN
NAVFACENGCOM CONTRACTS / ROICC, Point Mugu, CA
NAVFACENGCOM CONTRACTS / ROICC, Keflavik, Iceland, FPO New York,
NAVFACENGCOM CONTRACTS / SW PAC, OICC, APO San Francisco,
NAVFACENGCOM CONTRACTS / Trident, OICC, Saint Marys, GA
NAVFACENGCOM LANTDIV / BR OFC, DIR, Naples, Italy, FPO New York,
NAVFACENGCOM LANTDIV / Code 1112, Norfolk, VA
NAVFACENGCOM NORTHDIV / CO, Philadelphia, PA
NAVFACENGCOM NORTHDIV / CO, Philadelphia, PA

NAVFACENGCOM NORTHDIV / Code 04, Philadelphia, PA
NAVFACENGCOM NORTHDIV / Code 111, Philadelphia, PA
NAVFACENGCOM NORTHDIV / Code 202.2, Philadelphia, PA
NAVFACENGCOM PACDIV / Code 09P, Pearl Harbor, HI
NAVFACENGCOM PACDIV / Code 2011, Pearl Harbor, HI
NAVFACENGCOM SOUTHDIV / Code 04A3, Charleston, SC
NAVFACENGCOM SOUTHDIV / Code 0525, Charleston, SC
NAVFACENGCOM SOUTHDIV / Code 1021F, Charleston, SC
NAVFACENGCOM SOUTHDIV / Code 102H, Charleston, SC
NAVFACENGCOM SOUTHDIV / Code 4023, Charleston, SC
NAVFACENGCOM SOUTHDIV / Code 405, Charleston, SC
NAVFACENGCOM SOUTHDIV / Code 406, Charleston, SC
NAVFACENGCOM WESTDIV / Code 04A2.2 Lib, San Bruno, CA
NAVFACENGCOM WESTDIV / Code 04B, San Bruno, CA
NAVFACENGCOM WESTDIV / Code 09B, San Bruno, CA
NAVFACENGCOM WESTDIV / Code 09P/20, San Bruno, CA
NAVFACENGCOM WESTDIV / Code 102, San Bruno, CA
NAVFACENGCOM WESTDIV / Code 403.2 (Kelly), San Bruno, CA
NAVFACENGCOM WESTDIV / Code 406.2 (Smith), San Bruno, CA
NAVFACENGCOM WESTDIV / Code 408.2 (Jeung), San Bruno, CA
NAVFACENGCOM WESTDIV / PAC NW Br Offc, Code C/42, Silverdale, WA
NAVFUEL DET / OIC, FPO Seattle,
NAVHOSP / CO, Millington, TN
NAVHOSP / Hd, Fac Mgmt, Camp Pendleton, CA
NAVHOSP / PWO, FPO Seattle, WA
NAVHOSP / ROICC Offc (Watson), Beaufort, SC
NAVHOSP / SCE (Knapowski), Great Lakes, IL
NAVHOSP / SCE, FPO San Francisco,
NAVHOSP / SCE, Newport, RI
NAVHOSP / SCE, FPO Seattle,
NAVMAG / SCE, FPO San Francisco,
NAVMARCORESCEN / LTJG Davis, Raleigh, NC
NAVMEDCOM / NWREG, Fac Engr, PWD, Oakland, CA
NAVMEDCOM / PACREG, Code 22, Barbers Point, HI
NAVMEDCOM / SCE, Jacksonville, FL
NAVMEDCOM / SWREG, Code 35, San Diego, CA
NAVMEDCOM / SWREG, SCE, San Diego, CA
NAVMEDRSCHINSTITUTE / Code 47, Bethesda, MD
NAVOCEANCOMCEN / Code EES, FPO San Francisco,
NAVOCEANO / Code 6200 (M Paige), NSTL, MS
NAVOCEANO / Lib, NSTL, MS
NAVOCEANSYSCEN / Code 9642B, San Diego, CA
NAVORDSTA / Code 0922B1, Indian Head, MD
NAVPETOFF / Sec Offr (Code 20), Alexandria, VA
NAVPETRES / Dir, Washington, DC
NAVPGSCOL / Code 1424, Lib, Monterey, CA
NAVPGSCOL / Code 68WY (Wyland), Monterey, CA
NAVSEASYSCOM / Code 05M3, Washington, DC
NAVSECGRU / Code G43, Washington, DC
NAVSECGRUACT / CO, FPO Miami,
NAVSECGRUACT / PWO (Code 40), Edzell, Scotland, FPO New York,
NAVSECGRUACT / PWO, FPO Miami,
NAVSECSTA / Code 60, Washington, DC
NAVSHIPREPFAC / SCE, FPO Seattle,
NAVSHIPYD / Carr Inlet Acoustic Range, Bremerton, WA
NAVSHIPYD / CO, Philadelphia, PA
NAVSHIPYD / Code 134, Pearl Harbor, HI
NAVSHIPYD / Code 202.4, Long Beach, CA
NAVSHIPYD / Code 202.5 Lib, Bremerton, WA
NAVSHIPYD / Code 308.05, Pearl Harbor, HI
NAVSHIPYD / Code 308.3, Pearl Harbor, HI
NAVSHIPYD / Code 382.3, Pearl Harbor, HI
NAVSHIPYD / Code 443, Bremerton, WA
NAVSHIPYD / Mare Is, Code 106.4, Vallejo, CA
NAVSHIPYD / Mare Is, Code 202.13, Vallejo, CA
NAVSHIPYD / Mare Is, Code 280, Vallejo, CA
NAVSHIPYD / Mare Is, Code 401, Vallejo, CA
NAVSHIPYD / Mare Is, Code 457, Vallejo, CA
NAVSHIPYD / Mare Is, PWO, Vallejo, CA
NAVSHIPYD / Norfolk, Code 380, Portsmouth, VA
NAVSHIPYD / PWO (Code 400), Long Beach, CA
NAVSHIPYD / PWO, Bremerton, WA
NAVSHIPYD / Tech Lib, Portsmouth, NH
NAVSTA / A. Sugihara, Pearl Harbor, HI
NAVSTA / CO, Long Beach, CA
NAVSTA / CO, FPO Miami,
NAVSTA / CO, Brooklyn,, NY
NAVSTA / Code 4216, Mayport, FL
NAVSTA / Code 423, Norfolk, VA
NAVSTA / Code N4214, Mayport, FL
NAVSTA / Engrg Dir, PWD, Rota, Spain, FPO New York,
NAVSTA / PWO, Guantanamo Bay, Cuba, FPO New York,
NAVSTA / PWO, Rota, Spain, FPO New York,
NAVSTA / Util Engrg Offr, Rota, Spain, FPO New York,
NAVSTA/ Code 423, FPO Norfolk, VA
NAVSUPPACT / CO, Naples, Italy, FPO New York,
NAVSUPPFAC / Contract Admin Tech Lib, FPO San Francisco,
NAVSUPPO / Sec Offr, La Maddalena, Italy, FPO New York,
NAVSUPSYSCOM / Code 0622, Washington, DC
NAVSWC / Code E211 (Miller), Dahlgren, VA
NAVSWC / Code G-34, Dahlgren, VA
NAVSWC / Code W41C1, Dahlgren, VA
NAVSWC / Code W42 (GS Haga), Dahlgren, VA
NAVSWC / DET, White Oak Lab, Code W50, Silver Spring, MD
NAVUSEAWARENGSTA / Code 073, Keyport, WA
NAVWPNCEN / AROICC, China Lake, CA
NAVWPNCEN / Code 2634, China Lake, CA
NAVWPNCEN / Code 2637, China Lake, CA
NAVWPNSTA / PWO, Yorktown, VA
NAVWPNSTA EARLE / Code 092, Colts Neck, NJ
NAVWPNSTA EARLE / PWD (Lengyel), Colts Neck, NJ
NAVWPNSTA EARLE / PWO (Code 09B), Colts Neck, NJ
NBS / Bldg Mat Div, Mathey, Gaithersburg, MD
NBS / Bldg Tech, McKnight, Gaithersburg, MD
NCR / 20, CO, Gulfport, MS
NCR / 20, Code R70, Gulfport, MS
NEASE, A.D., JR / Panama City, FL
NEESA / Code 111E (McClaine), Port Hueneme, CA
NEESA / Code 113M2, Port Hueneme, CA
NETPMSA / Tech Lib, Pensacola, FL
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NEW YORK STATE MARITIME COLLEGE / Longobardi, Bronx, NY
NMCB / 3, Ops Offr, FPO San Francisco,
NMCB / 40, CO, FPO San Francisco,
NMCB / 5, Ops Dept, FPO San Francisco,
NMCB / 74, CO, FPO Miami,
NOAA / Joseph Vadus, Rockville, MD
NOAA / Lib, Rockville, MD
NORDA / Code 1121SP, NSTL, MS
NORDA / Code 352, NSTL, MS
NORTHDIV CONTRACTS OFFICE / ROICC, Colts Neck, NJ
NORTHWESTERN UNIV / CE Dept (Dowding), Evanston, IL
NRL / Code 2511, Washington, DC
NRL / Code 2530.1, Washington, DC
NRL / Code 6123, Washington, DC
NRL / Code 6127, Washington, DC
NSC / Code 43, Oakland, CA
NSC / Code 700, Norfolk, VA
NSC / PWO, Williamsburg, VA

NSC / SCE, Norfolk, VA
NUHN & ASSOC / A.C. Nuhn, Wayzata, NM
NUSC DET / Code 2143 (Varley), New London, CT
NUSC DET / Code 3322 (Brown), New London, CT
NUSC DET / Code 44 (Munn), New London, CT
NUSC DET / Code 5202 (Schady) New London, CT
NUSC DET / Code TA131, New London, CT
NUSC DET / Lib, Newport, RI
NY CITY COMMUNITY COLLEGE / Lib, Brooklyn, NY
OCNR / Code 1114SE, Arlington, VA
OCNR / Code 1121 (EA Silva), Arlington, VA
OCNR / Code 1234, Arlington, VA
OCNR / NRL (Prout), Alexandria, VA
OFFICE OF SEC OF DEFENSE / OASD (P&L)E, Washington, DC
OREGON STATE UNIV / CE Dept (Hicks), Corvallis, OR
OREGON STATE UNIV / CE Dept (Yim), Corvallis, OR
OREGON STATE UNIV / Oceanography Scol, Corvallis, OR
PACIFIC MARINE TECH / M. Wagner, Duvall, WA
PADILLA, L.M. / Oxnard, CA
PAULI, DC / Silver Springs, MD
PENNSYLVANIA STATE UNIV / Rsch Lab, State College, PA
PETERSEN, CAPT N.W. / Pleasanton, CA
PHIBCB / 1, CO, San Diego, CA
PHIBCB / 1, P&E, San Diego, CA
PHIBCB TWO / CO, Norfolk, VA
PHILADELPHIA ELEC CO / E. D. Freas, West Chester, PA
PILE BUCK, INC / Smoot, Jupiter, FL
PMTC / Code 5041, Point Mugu, CA
PRESNELL ASSOC, INC / DG Presnell, Jr, Louisville, KY
PURDUE UNIV / Engrg Lib, West Lafayette, IN
PWC / ACE Office, Norfolk, VA
PWC / CO, Oakland, CA
PWC / Code 10, Oakland, CA
PWC / Code 101, Great Lakes, IL
PWC / Code 1011, Pearl Harbor, HI
PWC / Code 102, Oakland, CA
PWC / Code 110, Oakland, CA
PWC / Code 30, Great Lakes, IL
PWC / Code 400, Great Lakes, IL
PWC / Code 400, FPO San Francisco,
PWC / Code 400, San Diego, CA
PWC / Code 400, Pearl Harbor, HI
PWC / Code 400, Oakland, CA
PWC / Code 412, San Diego, CA
PWC / Code 420, Oakland, CA
PWC / Code 420B (Waid), FPO San Francisco,
PWC / Code 421 (Kaya), Pearl Harbor, HI
PWC / Code 421 (Quin), San Diego, CA
PWC / Code 421 (Reynolds), San Diego, CA
PWC / Code 422, San Diego, CA
PWC / Code 423, San Diego, CA
PWC / Code 423/KJF, Norfolk, VA
PWC / Code 430 (Kyi), Pearl Harbor, HI
PWC / Code 4450A (T. Ramon), Pensacola,
PWC / Code 50, Pensacola, FL
PWC / Code 500, Oakland, CA
PWC / Code 500, Great Lakes, IL
PWC / Code 505A, Oakland, CA
PWC / Code 590, San Diego, CA
PWC / Code 600, Great Lakes, IL
PWC / Code 610, San Diego, CA
PWC / Code 612, Pearl Harbor, HI
PWC / Code 614, San Diego, CA
PWC / Code 615, FPO San Francisco,
PWC / Code 700, San Diego, CA
PWC / Code 700, Great Lakes, IL
PWC / Lib, FPO San Francisco,
PWC / Util Dept (R Pascua), Pearl Harbor, HI
QUIRK, J / Panama City, FL
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ROBERT LYONS / Houston, TX
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ROOF INDUSTRY CONSULTANT / James E. Magowan, Dublin, CA
ROOFING INDUSTRY EDUCATIONAL INSTITUTE / Fricklas, Englewood, CO 80112
ROOFING MATERIALS SCIENCE AND TECHNOLOGY / Laaly, Los Angeles, CA
SAN DIEGO STATE UNIV / CE Dept (Noorany), San Diego, CA
SCIENCE APPS INTL CORP / Alexandria, VA
SEATTLE PORT / W Ritchie, Seattle, WA
SEATTLE UNIV / CE Dept (Schwaegler), Seattle, WA
SHIVE-HATTERY ENGINEERS INC. / George Kanz, P.E., Cedar Rapids, IA
SIMPSON, GUMPERTZ & HEGER, INC / Hill, Arlington, MA
SOCIETY OF THE PLASTICS INDUCTRY, INC / Polyurethane Foam Constractors Wash
SOUTHWEST RSCH INST / M. Polcyn, San Antonio, TX
SPCC / PWO, Mechanicsburg,, PA
SPIELVOGEL, L / Wyncote, PA
SRI INTL / J.L. Jones, Chem Engr Lab, Menlo Park, CA
STATE HOUSE / Off. of Energy Resources, Augusta, ME
STATE OF CONNECTICUT / Energy Div, Hartford, CT
STATE UNIV OF NEW YORK / CE Dept, Buffalo, NY
STATE UNIV OF NEW YORK / CE Dept, Buffalo, NY
STATE UNIV OF NEW YORK / Physio Dept, Buffalo, NY
STEPHENS, KNIGHT & SHERIDAN, INC. / Ralph Knight, Cincinnati, OH
STEVENS, TW / Dayton, OH
SUBASE / Bangor, PWO (Code 8323), Bremerton, WA
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